# LOW INPUT VOLTAGE D. C TO D. C. CONVERTER

## FINAL REPORT

Contract Number NAS 5-3441

National Aeronautics and Space Administration

26 June 1963 to 26 March 1964

Object: The object of this contract is to design and develop an efficient, reliable low voltage D. C. to high voltage D. C. regulated converter using germanium power transistor switching elements. This converter will be used to convert the low voltage levels of newly developed energy sources to useful higher levels.

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# SECTION I

# PURPOSE

The purpose of this contract is to design and to develop an efficient, reliable, and lightweight, low voltage dc to high voltage dc regulated converter, using germanium transistors as the power switching element. The converter will be designed to convert the output of thermionic diodes, thermoelectric generators, fuel cells, solar cells, and high performance, single cell electrochemical batteries to a regulated 28 volt dc output. The program includes circuit configuration selection, optimization, and new design efforts to reduce losses, size and weight. Effort will be directed toward construction of a breadboard model to verify that the design goals and performance requirements have been optimized.

## SECTION II

## SUMMARY

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During this program, research and development effort was concentrated on the determination of the optimum design of transistor low input voltage converters to convert the low voltage power of new energy sources up to useful levels for space applications. This study showed that transistor low input voltage converter-regulators have the performance characteristics to efficiently convert the low voltage power to a useful higher voltage.

Initial investigations determined that a current feedback transistor power oscillator should be used to chop the low voltage. high current power to square wave ac and transform it to higher voltage. This circuit is superior because it maintains optimum efficiency throughout the load range and is virtually independent of input voltage changes and transistor parameter variations which may occur with temperature or from aging. It was determined, that voltage regulation by pulse width modulation of the stepped up and rectified converter output provides the maximum efficiency consistent with system operation. The excellent efficiency, regulation, and performance over wide input voltage, load, and ambient temperature ranges has been verified by measurements on a converter-regulator model which was fabricated, tested, and shipped to NASA-Goddard.

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This model was designed to operate from a 0.8 to 1.6 volt source, and provide a 50 watt regulated 28 volt output. High efficiency (over 70%) was maintained throughout the specified input voltage, load, and ambient temperature range (-10° C to +70° C). With higher input voltages, the converter was capable of providing much more than the rated 50 watt output. The converter also performed satisfactorily over a wider ambient temperature range than required (-54° C to +70° C).

Transformer taps were provided in the model to accomodate a narrower input voltage range of 1.2 to 1.6 volts. When connected for this narrower range, efficiencies exceeded 75% at heavy load.

An overload protection circuit has been provided which has fast response, limits the output current to a preset level under dead short or overload conditions, and will immediately pick up the rated load when the overload is removed.

The families of uniform performance curves and data included in this report provide additional detail and verify that high efficiencies and excellent voltage regulation are obtained over wide input voltage, load, and ambient temperature ranges.

Reliability predictions indicate that converter-regulators can achieve high reliabilities. The estimated reliabilities included herein will be useful to system designers considering the use of energy conversion source-low input voltage converter-regulator power systems. The high converter reliability should favor the use of a single source cell (or a minimum number of source cells) coupled to a converter for high reliability applications.

The 50 watt-packaged converter regulator model weighed 6.25 pounds. The converter power to weight ratio is somewhat low, and further effort should be directed toward weight reduction. This may be accomplished by the use of higher operating frequencies. It is desirable to improve the circuit switching speeds to achieve higher frequency operation and still maintain high efficiency.

The work done during this program has proven that transistor converter-regulators have the required efficiencies and performance characteristics necessary to convert the low voltage power of the new energy sources. It is now desirable to direct effort toward specific research and development areas associated with incorporating converter-regulators into high reliability systems for space applications. Further work should be directed toward the investigation of low voltage converter-regulators operating from various sources, the design of converters which will have lower weight, and investigation of techniques to minimize external magnetic field disturbance.

## SECTION III

## CONFERENCES

On February 11, 1964 Mr. J.T. Lingle, representing Honeywell, visited Mr. E.R. Pascuitti at NASA-Goddard Space Flight Laboratory to discuss technical details of this program. A bread board--converter-regulator was operated at the NASA--facility and the performance was observed by Mr. W.R. Cherry, Mr. F.C. Yagerhoffer, Mr. L. Viellette, and Mr. E.R. Pascuitti. Various circuit wave forms, efficiency, input and output ripple, and voltage regulation were measured and discussed. The effects of leakage inductance and transformer hysterisis loops on the oscillator switching characteristics were elaborated upon. The design and fabrication of the model to be delivered at the end of the program was explained. It was agreed that improved switching characteristics are desirable to allow higher frequency converter operation which will facilitate weight reduction of future devices.

## SECTION IV

## PROJECT DETAILS

### A. REVIEW OF PROGRAM WORK

The work during this program was directed at determining the best transistor circuit approach for a low input voltage dc to high voltage dc regulated converter which could be utilized in conjunction with the new energy sources to achieve a useable higher regulated output voltage for use in space craft. It was initially determined that a current feedback transistor power oscillator is the best method of converting the low voltage from the new energy sources to a higher voltage. The current feedback converter is best because:

a. It will operate from a low voltage source.

b. It will operate from a varying voltage source.

c. It will operate efficiently over a wide load range.

d. The feedback current is independent of input voltage variations, independent of transistor input impedance variations, and is proportional to load current.

e. The transistor can be overdriven with a minimum amount of drive power to assure a low saturation voltage under all conditions.

Performance data obtained from the current feedback circuits has shown that high efficiencies are obtained with varying input voltage and varying loads. Thus the circuit will work well with the new energy sources which may exhibit considerable variation in terminal voltage because of high internal impedance and variations in other parameters which effect the output voltage. The efficiency of the converter is optimized over the input voltage and load ranges because the power oscillator provides an optimum drive for all operating conditions. This is particularly important in a low input voltage converter because the transistor drive required is a function of the current carried. With low source voltages large collector currents are carried and hence the drive power required is an appreciable percentage of the power handled. Therefore the feedback drive power must be optimized proportional to load for all conditions. This does not present a problem in converters operating from higher voltage because the drive power is a much smaller percentage of the total power handled. However, in low input voltage converters, it is very important because of the large currents carried in proportion to the power converted. After the performance of the low input voltage power oscillator was established, the voltage regulation circuitry was next investigated.

To determine the best method of voltage regulation, two basic approaches were investigated. It was initially determined that some form of pulse width modulation voltage regulation must be used to operate at maximum efficiency and that this pulse width modulation should be accomplished in the secondary circuit where the transistor saturation losses would be a lower percentage of the power carried. The voltage regulator circuits examined included a voltage regulator which would pulse width modulate the output of the power transformer secondary by controlling the conduction time of the rectification circuit. The second regulation method used an "add-on" type switching regulator to pulse width modulate the dc output voltage at a higher frequency. Work on a related program established that the regulator which would vary the conduction time of the rectification circuit had the following disadvantages:

a. Pulse width modulation of the rectification circuit is reflected into the primary causing gating of current through the source, oscillator power transistors, and power transformer primary winding. This caused the power to flow through the primary circuit only during a portion of each half cycle.

b. Pulse width modulation of the rectification circuit decreased the basic converter efficiency due to higher collector currents during the conducting intervals.

c. Pulse width modulation of the rectification circuit increased the input line ripple.

Because the above disadvantages had been established in a related program, we did not construct a circuit of this type on this program. This prior experience and active work provided data which directed us to immediately investigate an "add-on" type pulse width modulation regulator in the dc output. Performance results on a low input voltage converter incorporating a switching type regulator in the output circuit showed that high overall efficiencies could be obtained. Performance showed that this circuit did not feed excessive ripple back into the power converter or back into the power source. This regulator used a filter capacitor between the rectification circuit and the pulse width modulation voltage regulator. This suppressed the ripple feedback and allowed the low voltage converter to operate at its maximum efficiency independent of the regulator time sharing period. The filter capacitor also prevented the pulse width modulation effect from being fed back into the source. The regulator was operated at a higher frequency to reduce the size of filter components.

This type of voltage regulator should work well with the new energy sources because it will not cause excessive ripple or inverse currents to be fed back to the source. The frequency response of this regulator is also higher than could be obtained with a regulator which would pulse width modulate the rectification circuit.

Both germanium and silicon transistors were used as pulse width modulators. The small signal circuitry was silicon; however, germanium pulse width modulator transistors were used to achieve a slightly higher efficiency. With an all silicon pulse width modulation regulator, the efficiency was approximately 2% lower.

Synchronization of the power oscillator circuit was also investigated. One of the more important reasons for investigating the synchronization circuit was that the transistors could be back biased to a higher voltage to achieve more rapid switching and to provide higher efficiency. The higher back bias voltage could be achieved because the transistor "switching off" was decoupled from the current feedback transformer. This removed a voltage clamp formed by the transformer winding and input impedance of the conducting transistor. Decoupling allowed us to back bias the "switching off" transistor to a higher voltage because the "clamp" was removed. A higher back bias voltage was achieved by the resetting action of a choke coil between the two power oscillator transistor bases. This synchronizing circuit was found to work well and would back bias the transistors to a higher voltage; however, the circuit was considerably more complex than the simple circuit eventually used. Circuit tests showed that it was unnecessary to synchronize the power oscillator at a fixed frequency to achieve satisfactory voltage regulation. Therefore, the synchronization approach was dropped in favor of a simpler frequency control circuit which would control power oscillator frequency proportional to the input voltage. This simpler circuit would allow the operating frequency to increase as the input voltage increased and thereby hold the transformer operating flux nearly constant and prevent saturation of the output transformer.

After the converter and regulator circuitry were firmly established, the overload protection circuit was next investigated. Initially, the overload was sensed by a current transformer connected in series with the secondary of the power transformer. Tests on the converter regulator breadboard showed that this circuit would function. However, the following difficulties were noted:

a. The overload current flowing through the current transformer was a false indication of output power since this current was measured at the unregulated output of the converter and with higher input voltages the secondary current was lower for a given overload current. Thus, the point at which the overload circuit operated varied depending upon the converter input voltage.

b. High current surges would flow through the regulator transistor when the overload was suddenly removed. This required two parallel-connected power transistors in the pulse width modulator to handle the high surge current. This current surge was caused by a charged capacitor discharging through the regulator transistors into the other filter capacitor when the overload was suddenly removed.

Because of these difficulties, the overload sensing circuit was moved from the secondary circuit to the negative output line. This arrangement sensed the true output overload current so that the overload protection circuit would trip at a specific overload current which was independent of input voltage. The overload circuit sensed current flow into the output filter capacitor as well as the load. When the overload was suddenly removed, this circuit would prevent high surge currents from flowing from one filter capacitor to the other,thereby preventing excessive current flow through the regulating transistor. Thus, sensing the overload in the output circuit provided improved performance by:

a. being able to control the initiating point of the current limiting circuit more accurately;

b. limiting the amount of surge current flowing through the pulse width modulation transistor during application and removal of overload.

Since the high surge currents through the pulse width modulator were eliminated it was possible to remove one of the parallel-connected modulating transistors and further simplify the circuit.

After the overall converter regulator circuit was established, extensive bread-board tests were performed to evaluate the circuit and to determine the optimum parameters for all components. After satisfactory completion of these tests, work was directed towards model design and model fabrication. A model was designed, fabricated, and then tested to verify that the performance goals were achieved.

Electro-plated aluminum bus bars were used to reduce the weight of the converter model. Thermal problems were considered in the design. The germanium transistors were thermally connected to the chassis to provide adequate heat transfer and to minimize temperature effects. A thermal-shunt was placed in the input circuit to minimize heat flow from a high temperature source into the converter. The model was designed to operate over an 0.8 to 1.6 volt input. Transformer taps were provided so that the model could also be operated over a 1.2 volt to 1.6 volt range at a slightly higher overall efficiency. The model was tested at high and low temperature environments with the transformer connected for each input voltage range. The performance tests showed that the model achieved higher efficiencies than required, especially when the 1.2 to 1.6 volt connections were used. These results are discussed in detail later.

## B. CIRCUIT DESIGN

### 1. Block Diagram

The converter-regulator block diagram is shown on Figure 1. The circuit consists of a small starting oscillator to guarantee starting under all environmental conditions;a current feedback power oscillator to chop the low voltage high current power to ac and transform it to higher voltage; a rectification and filter circuit to rectify the power to dc; a voltage regulator consisting of a sawtooth ramp generator, a differential detector, a snap acting amplifier, a power transistor chopper, and an output filter circuit to regulate and filter the output; and an overload limiting circuit to provide overload protection.

### 2. Circuit Diagram

The circuit diagram is shown on Figure 2. This circuit is nearly identical to the circuit described in Progress Report II. The starting circuit, the current feedback power oscillator and the frequency control circuit is identical to that shown in Progress Report II. Most of the voltage regulator circuitry is also similar. The overload protection circuit has been completely changed. Referring to the circuit diagram shown on page 8 of Progress Report II, we can note that the current transformer formally used to measure the overload current, (T4), has been removed. We can also note that one of the paralleled chopping transitors, Q6B, in the pulse width modulation regulator has been removed. Pulse transformer T5 and diode CR13 were also removed since it was found that this circuit had little effect upon the voltage regulator efficiency when the load was 50 watts or less. In the new overload protection circuit, shown on Figure 2 of this report, the overload current is sensed by resistor R35 which has a very low resistance. Voltage drop across this resistor is applied to a differential detector consisting of Q14 and Q15. This resistor is, in effect, connected between the bases of Q14 and Q15 through rheostat R30. Resistor R29 normally biases the base of Q14 so that it conducts more than Q15. However, during an overload,

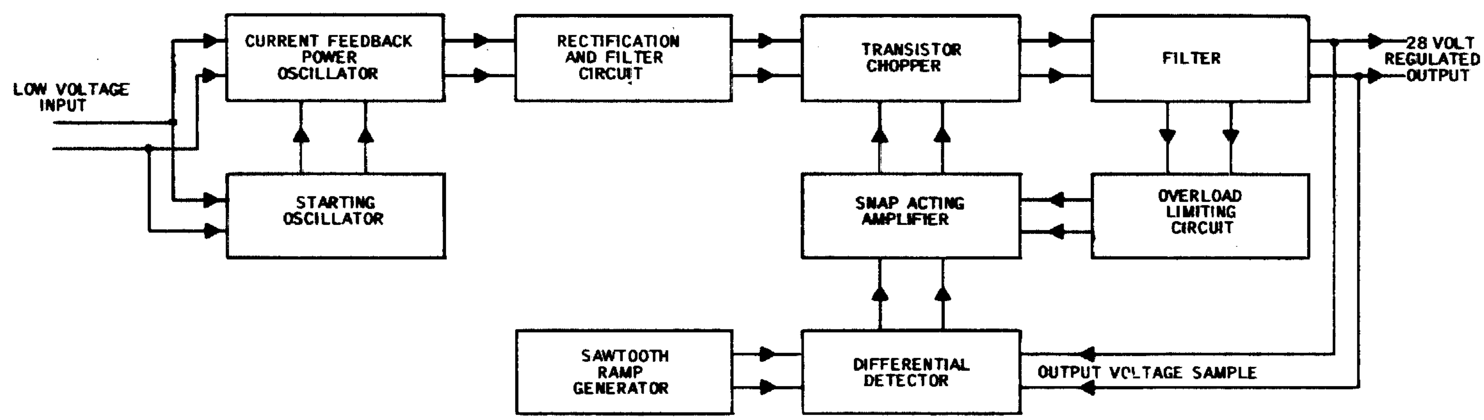


Figure 1 - CONVERTER-REGULATOR BLOCK DIAGRAM

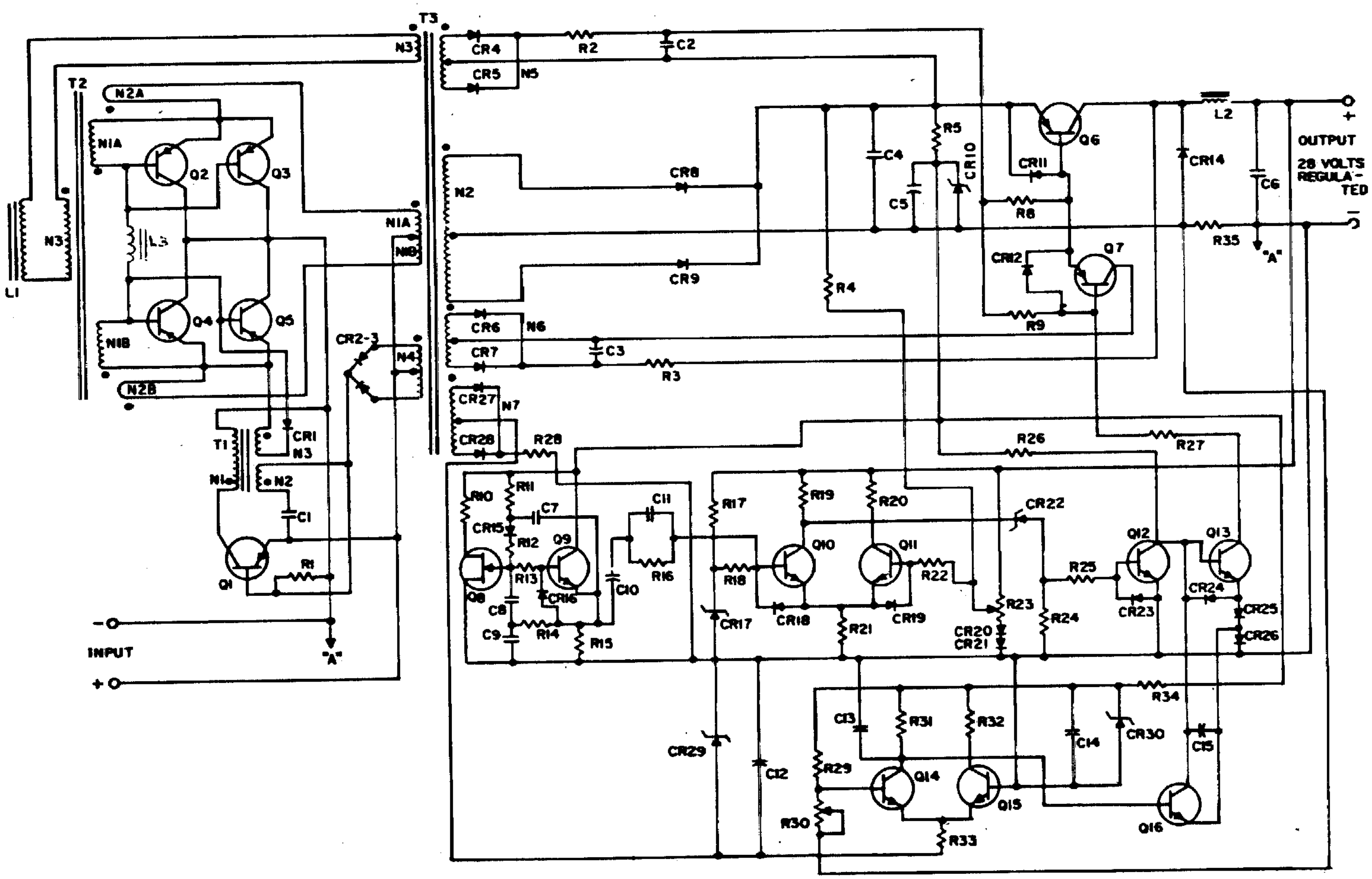


Figure 2 - LOW INPUT VOLTAGE CONVERTER-REGULATOR CIRCUIT DIAGRAM

an appreciable voltage will occur across R35 with a polarity such that the base of Q15 will tend to become more positive than the base of Q14. During overload then, Q15 will conduct more and Q14 less. The collector of Q14 will then become more positive and this will apply a signal to the base of Q16 and render it conductive. When Q16 conducts, it will tend to back bias Q13 shutting it off and also shutting off Q7 and Q6, thus removing power from the output. The circuit, of course, depends upon a voltage maintained across resistor R35 to maintain or to limit the output current. Thus, although this overload protection circuit does not completely shut off the output current, it limits it to a safe value which may be from 150 to 200% of the rated load current. Current pulses will flow though transistor Q6 to provide the limited overload current. The regulator continues to function and the overload protection circuit continues to sense the overload current. The output voltage, of course, will fall to a very low value or zero during overload. Resistor R35 is located between capacitor C4 and C6. Thus, when the overload is suddenly removed, the overload protection circuit will sense the dumping of energy from charged capacitor C4 through transistor Q6 into discharged capacitor C6. This circuit will respond instantly and will automatically limit the current flow to the predetermined overload level. This limits current transients through the regulator transistor, allowing it to operate safely within its rating. Thus, the new overload protection circuit limits the overload current to a safe level and also limits the surge current through the regulator transistor during the application and removal of overloads. Because the current is now safely limited in the pulse width modulator, only one chopping transistor is required in place of the two parallel-connected transistors formerly needed to handle surge current. Choke coil L2 limits surge currents for only a short interval since it will saturate for high current surges which last longer than a prescribed interval. A small negative supply has been incorporated in the converter to operate the new overload protection circuit. This consists of winding N7 and diodes CR27, 28, resistor R28, zener diode CR29, and filter capacitor C12. This negative supply provides the proper emitter potential for operating the overload sensing differential detector (Q14, Q15). The overload current limit set point can be adjusted by resistor R30. The remainder of the converter regulator circuit is identical to that described in Progress Report II, and is adequately explained in that progress report. The new overload protection circuit uses fewer and smaller parts than the previous circuit, reducing overall weight.

## C. TRANSFORMER DESIGN

After the circuit approach was finalized, design effort was directed toward the design of the circuit magnetic components. This was primarily concentrated on the current feedback transformer, the power transformer, and the output choke coil. One of the primary magnetic problems is a tendency for the feedback transformer and/or output transformer to operate with dc unbalance. This causes the transformer flux to operate unbalanced toward one side of the hysteresis loop and tends to saturate the transformer toward the end of one half cycle. The narrow square loop core material used is particularly susceptible to this type of operation. A slight variation in the length of successive oscillator half cycles or a slight variation in the impedance of each half of the primary circuit can contribute to non-symetrical operating flux. The condition is more predominant at lower frequencies where the core operating flux is closer to the saturation level. Since the core material has a narrow hysteresis loop, a small effective dc bias can cause this condition. When this condition occurs, the transformer will saturate towards one side of the hysteresis loop and the transistor collector current will increase sharply due to an increase in magnetizing current. The oscillator will switch shortly after this happens; however, the switching losses will be increased considerably because of the much higher currents carried during switching. Besides switching higher currents, the switching time also increases. These two effects tend to accelerate the increase in switching losses and the converter shows an appreciable decline in overall efficiency. During the switching interval, the half of the circuit that is switching "on" must increase its current rapidly so that it can overcome the magnetizing effect of the current still flowing in the circuit half that is switching "off." Higher currents and more time is required when the circuit half switching "off" is carrying a much higher collector current. The net result is that both transistors are conducting at the same time for a short interval and the total input current climbs to a very high value.

This effect has been minimized by controlling the operating frequency of the power oscillator circuit such that the frequency will be directly proportional to input voltage. This maintains the operating flux density at a nearly constant value which is much below the saturation flux density of the core materials. A small choke coil, L3, is also connected between the bases of the power oscillator transistors to provide an additional back bias switching signal during the switching interval. During switching, this choke coil attempts to maintain the same direction of current flow in its winding and reverses its polarity in doing so. This, in effect, introduces more energy into the drive circuit during the switching interval to achieve more rapid switching of the power oscillator and to diminish the effects of unsymmetrical operation on the hysteresis loop.

Primary and secondary leakage inductances also contribute to this effect. If the secondary current declines more rapidly than the primary current during the switching interval, then the net magnetizing current can still increase even though the primary current is decreasing. This results from the fact that the effective load current is decreasing rapidly and the magnetizing current can continue to increase with a decreasing primary current under these conditions. The higher effective magnetizing current during the switching interval will require more magnetizing current in the oscillator half that is switching "on" and hence will increase the switching time. Primary leakage inductance will also contribute to this effect since it will tend to maintain the flow of current in the transistor oscillator half that is switching "off." Thus to achieve optimum switching, several parameters must be controlled to prevent excessive currents during switching and to prevent excessive switching time.

Two core material types have been used in the power transformer. These are "Deltamax and "Supermalloy". Since the transformer cores used were the same size in both cases and the Supermalloy had a lower maximum flux density, the oscillator using Supermalloy core material was operated at a much higher frequency. No differences in power oscillator switching characteristics were noted when Supermalloy was used in place of Deltamax. The overall efficiency was approximately 4% lower with the Supermalloy core, and this reduced efficiency was due primarily to operation at approximately twice the frequency of the circuit using a Deltamax transformer core. Increased losses were due to an increased number of switching intervals in a fixed period at higher operating frequency. An oscillator using Supermalloy core material was operated at frequencies between 900 and 1960 cps. The operating efficiency decreased as the operating frequency was increased.

## D. MODEL DESIGN

A photograph of the low input voltage converter-regulator is shown in Figure 3. Some effort was directed at weight reduction in the design of this model. Weight reduction was primarily accomplished by the following:

a. The primary bus bars with large cross sectional areas were fabricated from electro-plated aluminum in place of copper to minimize the primary bus bar weight. The primary bus bars also serve as the transistor mounting brackets, thereby eliminating extra weight which may have resulted from the use of transistor mounting brackets.

b. The converter model has been laid out in a manner which minimizes the amount of chassis and supporting structure weight.

c. Components have been closely spaced and arranged to minimize the length of both the heavy primary bus work and the length of interconnecting lead wires.

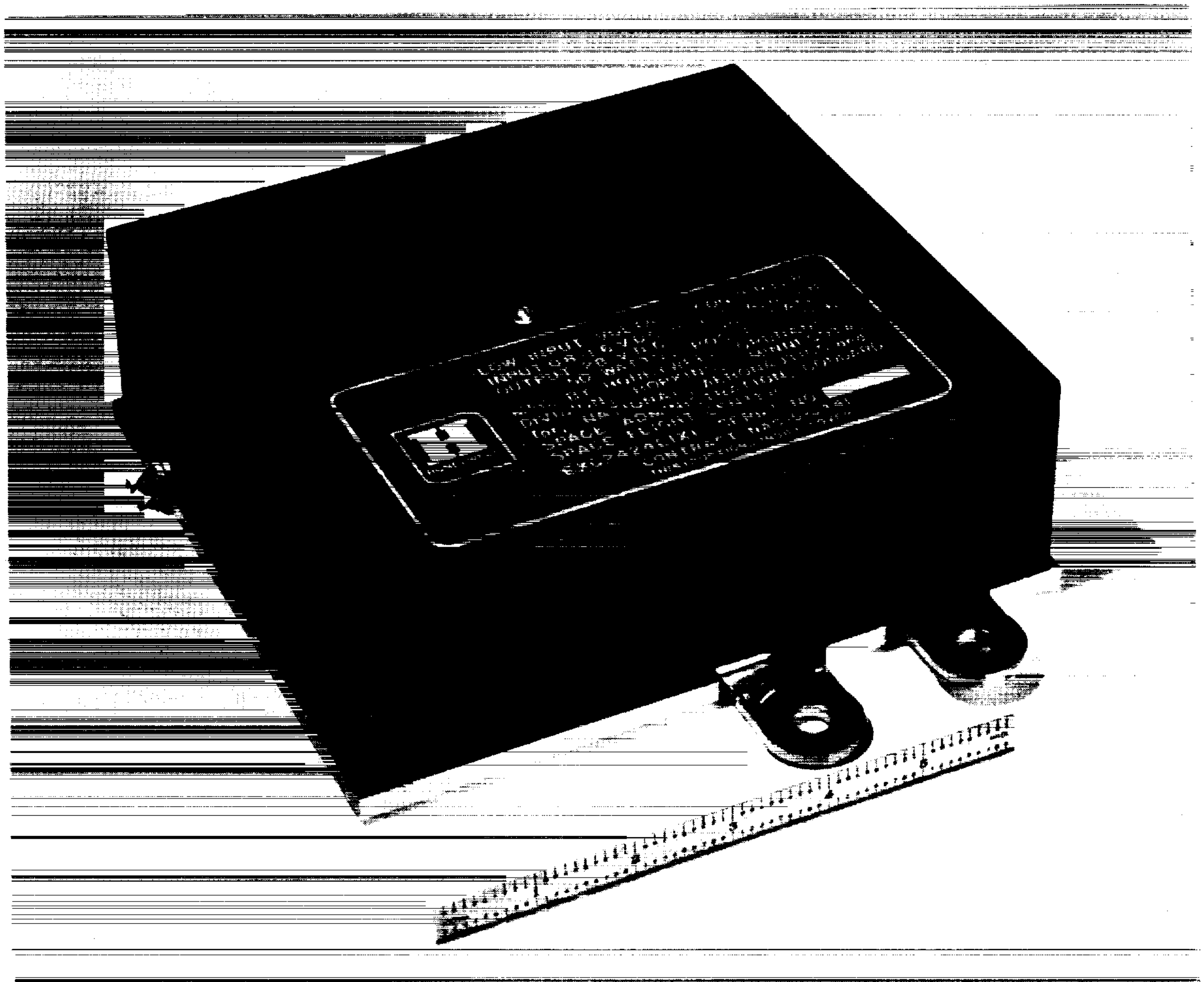

Figure 3 - LOW INPUT VOLTAGE CONVERTER-REGULATOR MODEL

d. The main chassis has been fabricated from 0.060-inch thick aluminum, and press studs and nuts have been utilized for mounting.

Heat transfer paths were considered in the model design. Primary effort was directed toward providing adequate thermal paths between the germanium transistors and the aluminum chassis. The germanium power oscillator transistors have been inserted into heavy aluminum clamps which are thermally connected directly to the converter chassis. This connection assures an excellent thermal path between the transistor junctions and the chassis. The chassis has a large flat bottomed surface that is suitable for mating with the surface of a heat sink to provide excellent heat transfer. The regulator chopping transistor is also mounted closely to the chassis with a suitable heat transfer path.

Particular emphasis has been placed upon the flow of heat from a possible high temperature source into the converter through the heavy input bus work. The negative input lead is connected directly to the chassis with large areas in contact. Therefore, any heat flow in the negative lead will go directly to the chassis where it can be dissipated into a heat sink. The positive input lead is mounted to the chassis with a thin sheet of mica electrical insulation between the positive bus bar and the chassis. The large areas in contact provide an adequate thermal path between the positive input lead and the chassis. This arrangement for both the negative and positive input leads provides a thermal shunt. Therefore, any heat flow from a high temperature source into the converter will be immediately shunted directly to the chassis through the large thermal paths which have large areas in contact. Any heat flowing in the positive input lead will have to flow through the power transformer primary winding before it can flow into the transistor emitters. This arrangement effectively prevents the flow of heat from a high temperature source to the germanium transistors used in the low input voltage converter-regulator.

Some effort has also been directed toward radio noise suppression. The regulator section which operates at a high frequency has been enclosed in a separate metal container. The output circuit contains large filter capacitors, and the output flows through a bulkhead-mounted feedthru capacitor to minimize radio noise.

## E. MODEL PERFORMANCE

The power transformer in the converter model contains taps to accommodate an input voltage in the range of 0.8 volts to 1.6 volts, or in the range of 1.2 volts to 1.6 volts. A higher overall efficiency can be obtained by using the 1.2 to to 1.6 volts taps when the input power is in this range. Changes from one connection to the other can be accomplished by changing the appropriate wires on the terminal board. An insert on the inside of the model cover describes the required connection changes for switching from one input range to the other. The converter model was first connected for the 1.2 to 1.6 volt range and run through an entire set of performance tests at environments ranging from -54°C to +70°C (-65°F to +158°F). The converter was tested for input voltages between 1.2 and 1.6 volts at various loads and overloads. After these tests were completed, the converter transformer connections were changed to the 0.8 to 1.6 volt range and the entire set of tests were reconducted. These tests were conducted over an environmental temperature range of -54°C to +70°C at various loads.

### 1. Efficiency

Data obtained from these performance tests is shown in Test Report OEXM 10610 (See Appendix A). The room temperature performance curves for the converter connected for a minimum input voltage of 1.2 volts is shown on Figure 4. The efficiency increased from slightly over 62% to slightly over 75% as the load was increased from 15 to 55 watts. The curve shows that the highest efficiency was obtained for the 1.2 volt input. The efficiency is highest

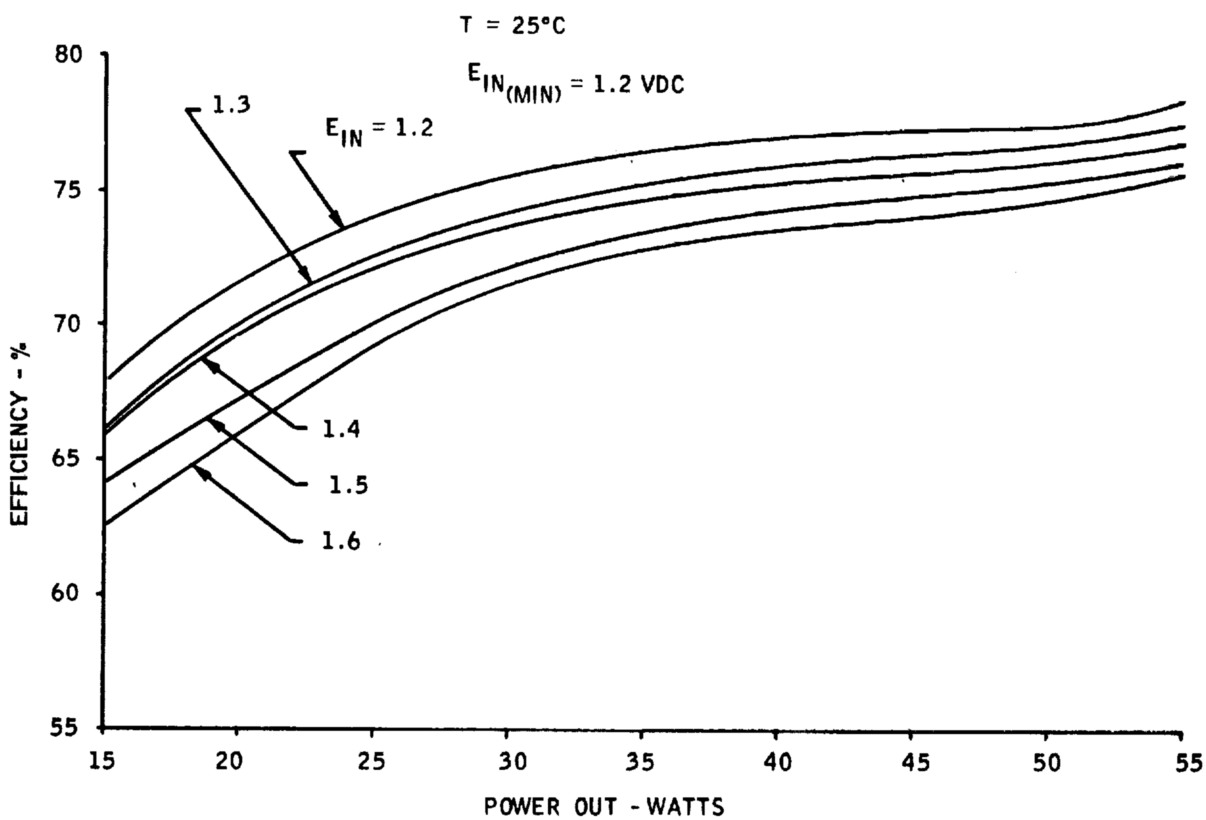


Figure 4 - CONVERTER-REGULATOR ROOM TEMPERATURE PERFORMANCE CURVES WHEN CONNECTED FOR INPUTS BETWEEN 1.2 AND 1.6 VOLTS

for the lower input voltage curve because the percent conduction time of the pulse width modulation voltage regulator is a greater portion of the cycle at the lower voltage. Conversely, for the higher input voltage, the percent conduction time is less and the power must flow through the regulator during a shorter period. This tends to increase the losses and the efficiency is approximately 3 to 5% lower. Note that the curves are uniformly spaced.

The curves show that the overall efficiency was above the design requirement of 70% for input voltages between 1.2 and 1.6 volts and loads exceeding 26 watts. The maximum efficiency recorded was obtained at loads of 55 watts. At this point the efficiencies ranged between 75.7% for a 1.6 volt input and 78.5% for the 1.2 volt input. At 50 watts load, the efficiencies ranged between 75% and 77.5% for input voltages between 1.6 and 1.2 volts, respectively. Figure 4 shows that the converter exceeded the design goal of 70% overall efficiency under these conditions, and it also indicates that the converter has a greater power capability than the required 50 watts since the efficiency is still increasing at loads of 55 watts. Efficiency at heavier load is discussed later.

Figure 5 shows the performance curves for the converter with the same connections operating at the minimum specified temperature, -10°C. The performance at the minimum specified temperature is nearly identical to the performance obtained at room temperature. High overall efficiencies are obtained in the 1.2 to 1.6 input voltage range with loads between 15 and 55 watts. The efficiency at 50 watts load varies between 75% and 77.5% for input voltages between 1.6 and 1.2 volts, respectively. Figure 5 shows that the converter operates well at the -10°C lower limit. The efficiency is still increasing at 55 watts load which indicates that the converter could supply higher output power at this same efficiency.

The converter was also operated at a temperature much lower (-54°C) than the -10°C specification requirement. Converter performance at -54°C is shown on Figure 6. These curves are similar to the room temperature and -10°C curves in that very high efficiencies were obtained with inputs between 1.2 and

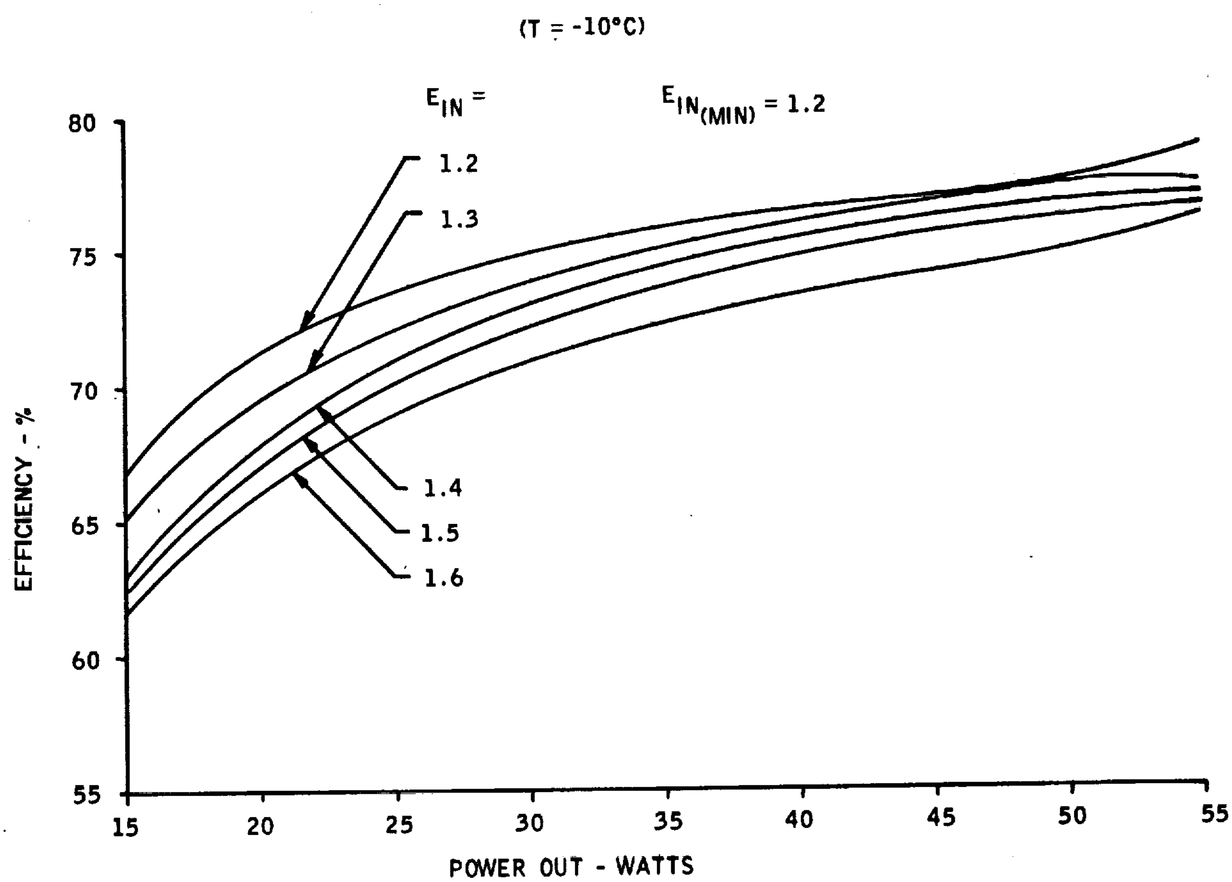


Figure 5 - CONVERTER MODEL PERFORMANCE WHEN OPERATING AT -10°C WITH INPUTS BETWEEN 1.2 AND 1.6 VOLTS

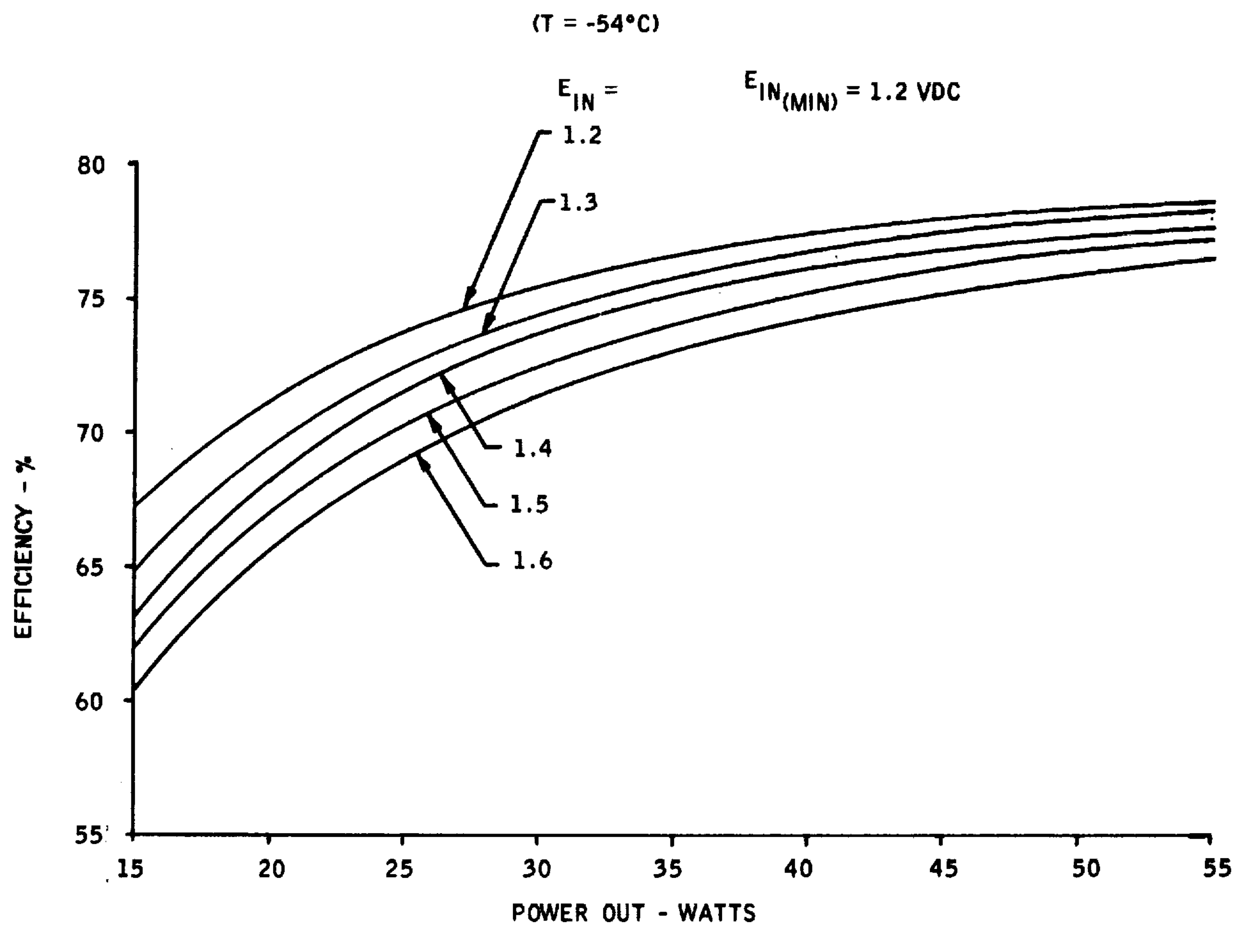


Figure 6 - MODEL PERFORMANCE WHEN OPERATING AT -54°C WITH INPUTS BETWEEN 1.2 AND 1.6 VOLTS

1. 6 volts over the 15 to 55 watt load range. The curves are uniformly spaced and show an increase in efficiency with load. The heavy load efficiency is slightly higher at low temperature due to a decline in conductor resistance. The efficiency is still increasing at 55 watts; hence, the converter is capable of supplying higher output power at these same high efficiencies. The converter was checked for starting and found to start satisfactorily at -54° C, with slowly rising input voltages.

Figure 7 shows the performance of this converter at the high temperature limit of +70° C. Note that this curve is similar to the curves obtained at the other ambient temperatures in that the curves are uniformly spaced, high efficiencies have been obtained, and the efficiency tends to increase as the load is increased. However, at high temperature the heavy load efficiency declined approximately 2%. At 50 watts load, the efficiencies range between 73. 8 and 76. 3%for input voltages between 1. 6 and 1. 2 volts, respectively. A slight increase in bus bar and transformer winding resistance at higher temperatures accounts for the slight efficiency decrease.

Converter performance data was also obtained at loads much greater than 50 watts. With the converter connected for the 1. 2 to 1. 6 volt range, performance data was obtained on the unit while operating at 1. 2 volts and 1. 6 volts at heavier loads and all environmenal temperatures.

Figure 8 shows the extra heavy load room temperature performance curves. With an 1. 2 volt input the maximum efficiency was obtained at 55 watts. The efficiency then declined from 78. 5% at 55 watts to 74% at 64 watts. However, for the higher input voltage the efficiency remained relatively high at approximately 75. 5% out to a load of 82. 5 watts. Thus the converter can deliver considerably more than the required 50 watts at a high efficiency when the input voltage is 1. 6 volts.

This same converter showed similar characteristics at -10° C as indicated on Figure 9. For the 1. 2 volt input, the maximum efficiency was slightly

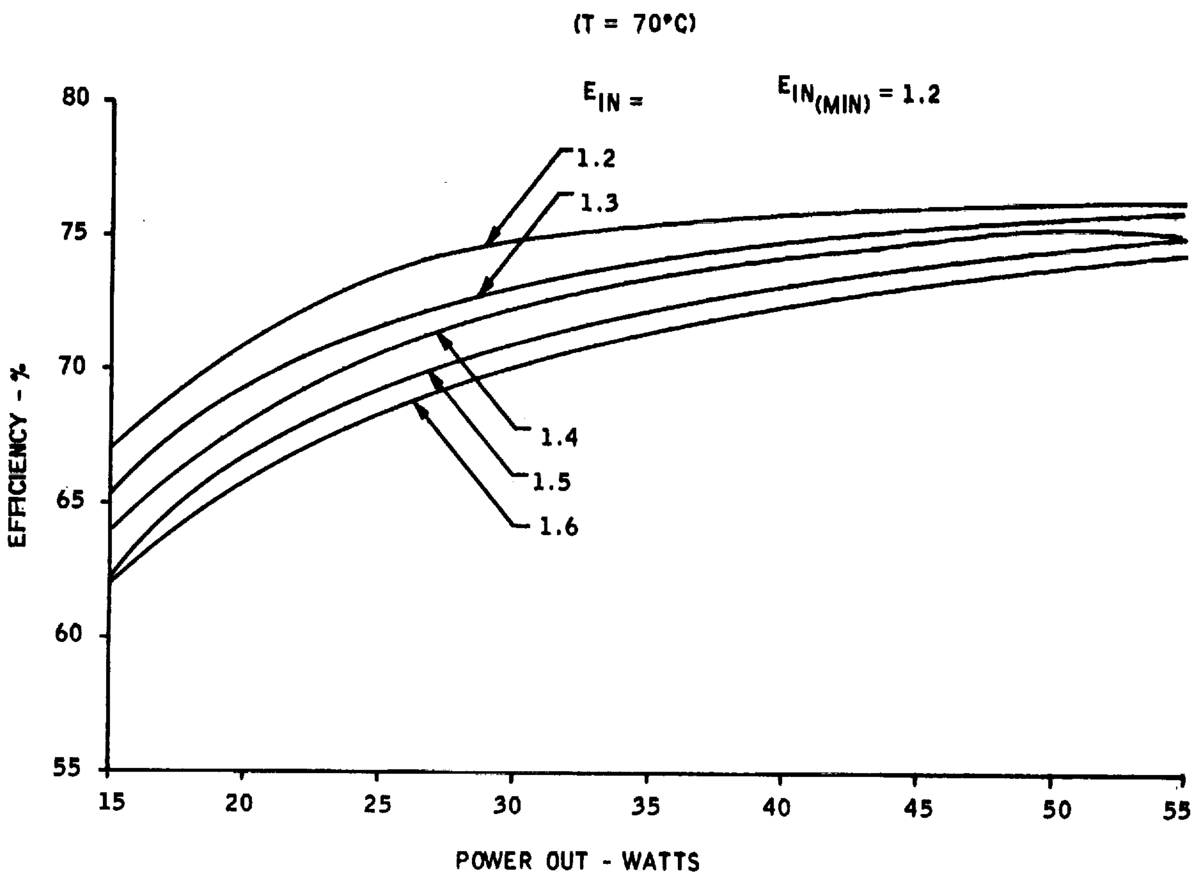


Figure 7 - MODEL PERFORMANCE WHEN OPERATING AT $\pm 70°C$ WITH INPUTS BETWEEN 1.2 AND 1.6 VOLTS

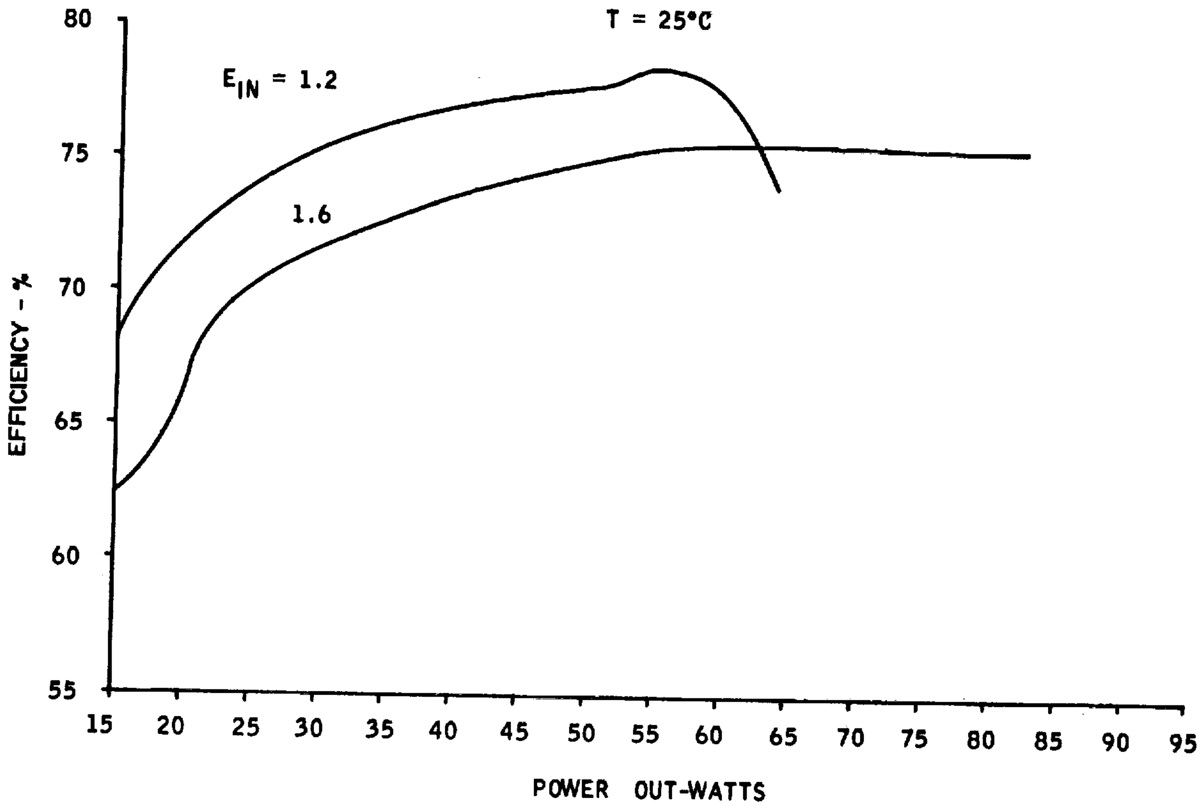


Figure 8 - ROOM TEMPERATURE MODEL PERFORMANCE WITH EXTRA HEAVY LOADS WHEN CONNECTED FOR THE 1.2 TO 1.6 INPUT VOLTAGE RANGE

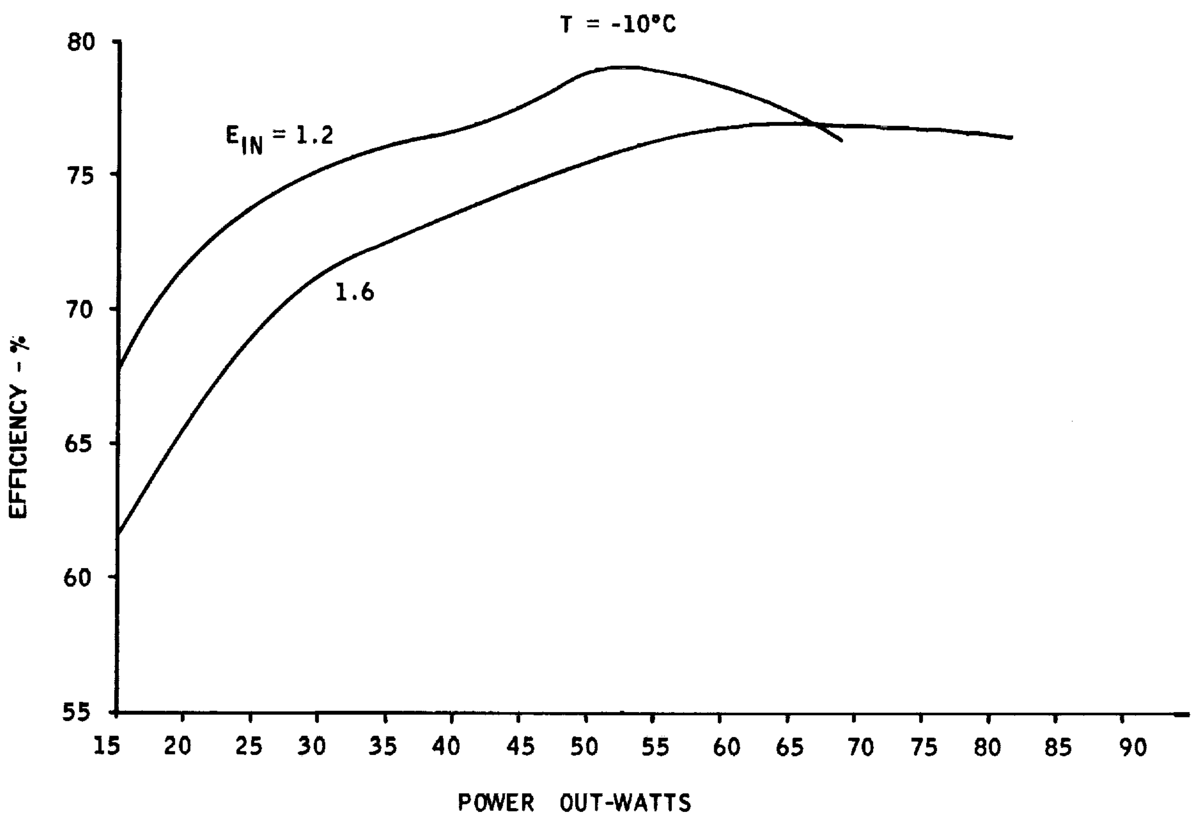


Figure 9 - MODEL PERFORMANCE AT EXTRA HEAVY LOAD WHEN OPERATING AT -10°C AND CONNECTED FOR THE 1.2 TO 1.6 INPUT VOLTAGE RANGE

higher at 79% and did not decline quite as much with heavier load. For this input, the converter delivered 69 watts at 76.3% efficiency. With a 1.6 volt input, the curve remained relatively flat out to a load of 82 watts, achieving 76.5% efficiency at 82 watts. The converter exhibited slightly improved performance and was capable of carrying a heavier load at high efficiency at this lower temperature.

The heavy load performance curves at -54° C shown on Figure 10 were also similar to the above two curves. With a 1.2 volt input, the maximum efficiency was approximately 78.5%, which declined to about 77% at 66.5 watts load. The 1.6 volt input curve showed an increase in efficiency with load and achieved an efficiency of 77.4% at 69.5 watts load.

Figure 11 indicates similar performance at the high temperature limit of 70° C. The curves were similar but increased copper resistance lowered the maximum efficiencies slightly. For the 1.2 volt input, the maximum efficiency was 77.4% at 55 watts, and this declined to 73.5% at 67.5 watts. Again, with a higher input voltage, the curve tended to be flatter and 74% efficiency was obtained at 83 watts load.

The above performance data has shown that the converter model works well over the required ambient temperature range and even works well at a much lower temperature of -54° C. When connected for the 1.2 to 1.6 volt range, the efficiency exceeds the required design goal of 70% over the load range of 30 to 55 watts for input voltages between 1.2 and 1.6 volts under all environmental conditions. For input voltages near the design minimum, the efficiencies are even higher and are maintained at lower loads. High efficiencies were obtained at loads much greater than 50 watts. With higher input voltages the maximum efficiencies occurred at loads exceeding 50 watts. This shows that the converter can provide much more than the rated 50 watt output with higher input voltages.

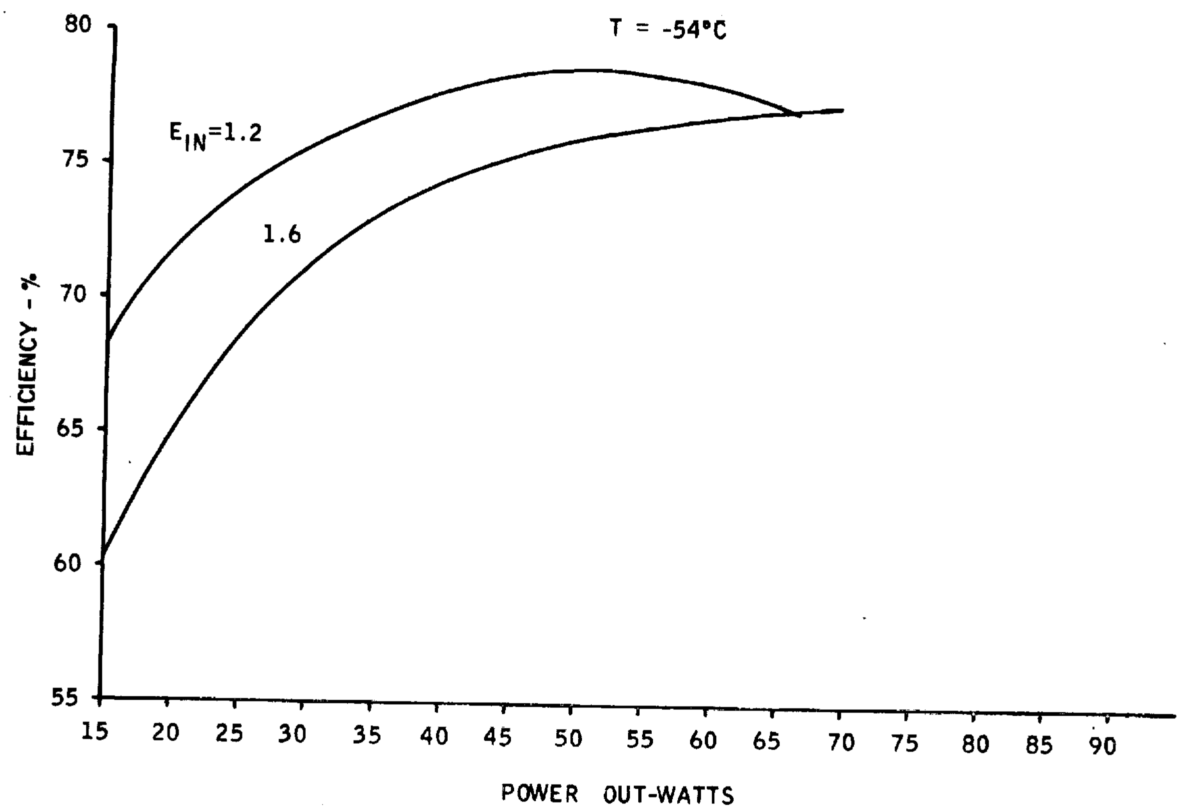


Figure 10 - MODEL PERFORMANCE AT EXTRA HEAVY LOAD WHEN OPERATING AT -54°C AND CONNECTED FOR THE 1.2 TO 1.6 INPUT VOLTAGE RANGE

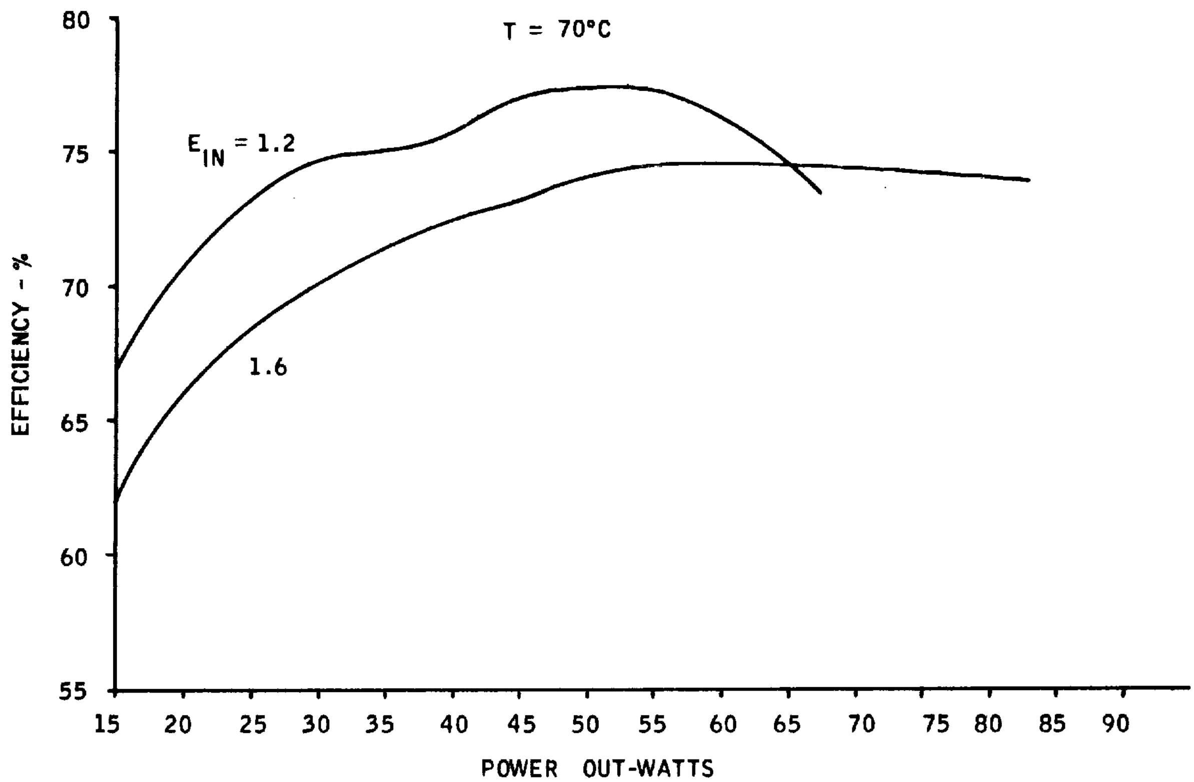


Figure 11 - HIGH TEMPERATURE MODEL PERFORMANCE AT EXTRA HEAVY LOAD WHEN CONNECTED FOR THE 1.2 TO 1.6 INPUT VOLTAGE RANGE

After tests were conducted for the converter connected for a 1. 2 to 1. 6 volt range, the transformer winding connections were changed to the wider input voltage range (0. 8 to 1. 6 volt). Performance data was then recorded for the converter connected for operation over the 0. 8 to 1. 6 input voltage range. Performance curves for the converter operating with this two to one change in input voltage are shown on Figure 12. These room temperature curves show that high efficiencies are obtained when the converter is connected for the lower voltages. Note that the highest efficiencies in the moderate load range are obtained with the lower input voltages of 0. 8 and 0. 9 volts. With a 0. 8 volt input, the maximum efficiency is 74% at 35 watts output. The efficiency then declines to approximately 71. 5% at 50 watts load. The efficiency for this 0. 8 volt input is above the 70% design goal for loads between 15 and 50 watts. The efficiency declines at heavier load with an 0. 8 volt input because the input current is much higher with a low input voltage for a given power output. Therefore, the $I^2R$ losses in the primary circuit are larger and cause a decline in efficiency at heavier load. For the lower input voltages the efficiency is higher at light load because the transformer core losses are less and because the regulator per cent conduction time is greater with a lower input voltage. As the input voltage is increased, the light load efficiency declines; however, the converter is capable of delivering more power with a higher input voltage and, consequently, the efficiency curve has less tendency to droop at heavier loads. Thus the curve for a 1 volt input shows no decline in efficiency out to 50 watts; instead, it shows a continual rise in efficiency as the load increases to 50 watts. The curves for higher input voltages such as 1. 4, 1. 5 or 1. 6 volts show an increase in efficiency as the load is increased. The slope of these curves indicate that the efficiency would increase as the load was increased beyond 55 watts. For the 1. 6 volt curve, the efficiency is slightly below 55% at 15 watts load and shows a smooth increase to 70% at 55 watts load. For higher loads, the efficiency would increase beyond 70%. This is discussed later. As pointed out before, the device efficiency is lower at the higher input voltage. The main reason for this lower efficiency is the reduction in regulator conduction time with higher input voltages. This short duty

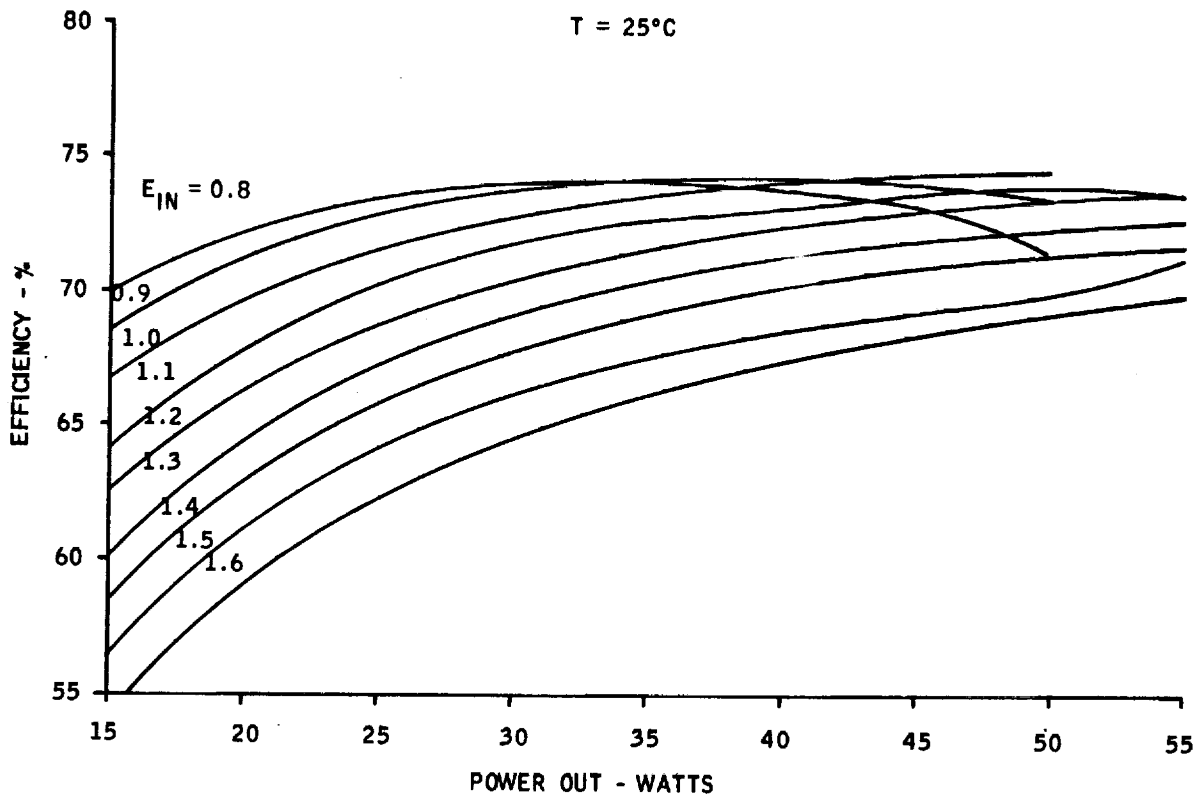


Figure 12 - ROOM TEMPERATURE MODEL PERFORMANCE WHEN OPERATING FROM INPUTS BETWEEN 0.8 AND 1.6 VOLTS

cycle causes increased copper and transistor losses because the power must flow through the regulator during a shorter interval. This performance curve indicates that as the converter-regulators are designed to accommodate wider input voltage swings, the overall efficiency at the higher input voltage will be less than that which could be obtained if the converter were designed for a narrower input voltage swing.

Figure 13 shows the performance curve of this converter operating at the minimum specified temperature of -10° C. Note that the family of curves is similar to the performance curves of Figure 12, except that higher efficiencies are obtained at the lower temperature. The maximum efficiency for an 0. 8 volt input was 79. 5% at 45 watts load and 79% at 53. 5 watts load. The higher efficiency of this device at -10° C can be attributed to a reduction in circuit resistance and probably also to an improvement in the transistor characteristics at this moderately low temperature. The efficiency is greater than the 70% design goal for loads in excess of 42 watts at all input voltages. The slope of the higher input voltage curves at 55 watts indicates that the converter would deliver considerably more power at higher efficiency with the higher input voltages.

Figure 14 shows the converter performance at a temperature much lower than required (-54° C). These curves follow the same general pattern as the other two curves discussed above and high efficiencies are obtained throughout the load range for all input voltages.

We do note, however, that for an 0. 8 volt input the maximum efficiency is slightly less than had been obtained at -10° C and the efficiency curve tends to droop slightly more at heavier loads. The copper losses are certainly less at -54° C; therefore, the slight decline in efficiency at heavier load at this temperature must be attributed to a decline in transistor characteristics at this low temperature. This decline presents no problems, however, since the overall efficiency of the device exceeds 75%, greater than the prescribed goal. Again, the slope of the curves for higher input voltages at

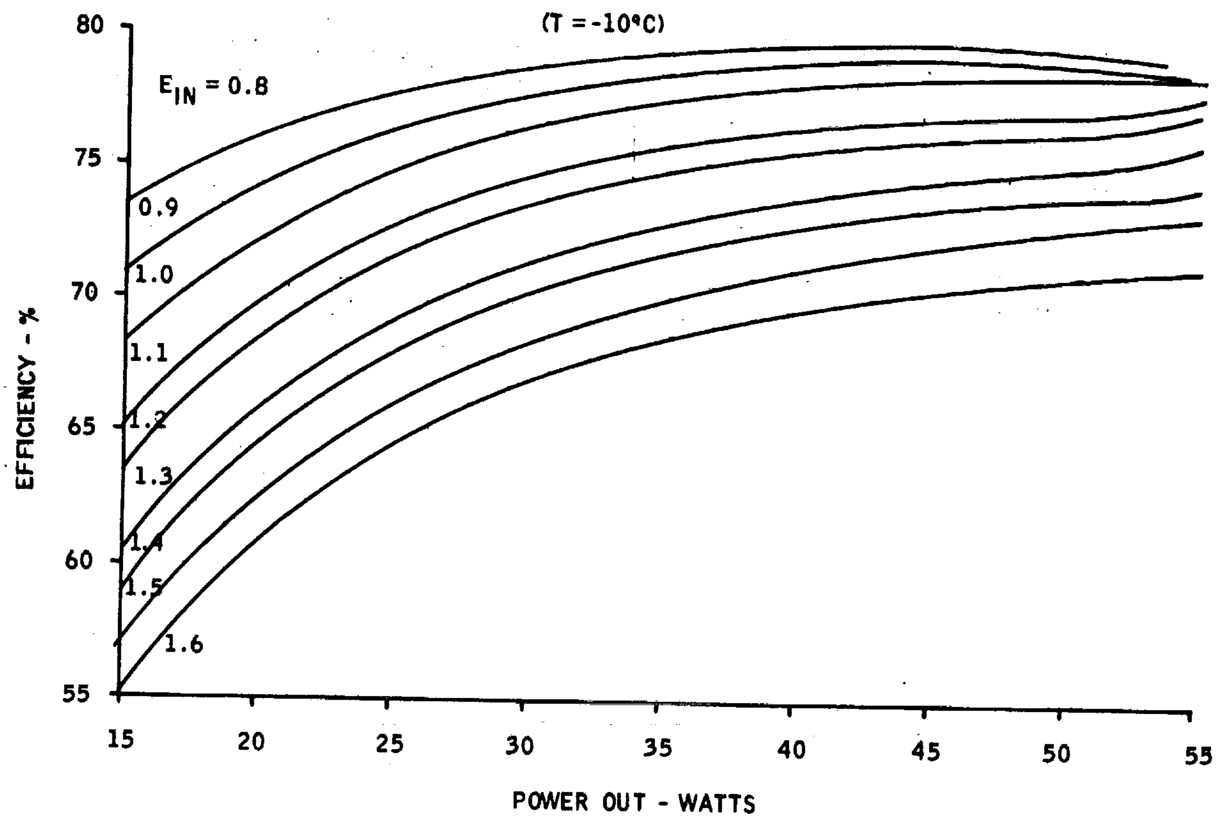


Figure 13 - MODEL PERFORMANCE WHEN OPERATING AT -10°C WITH INPUTS BETWEEN 0.8 AND 1.6 VOLTS

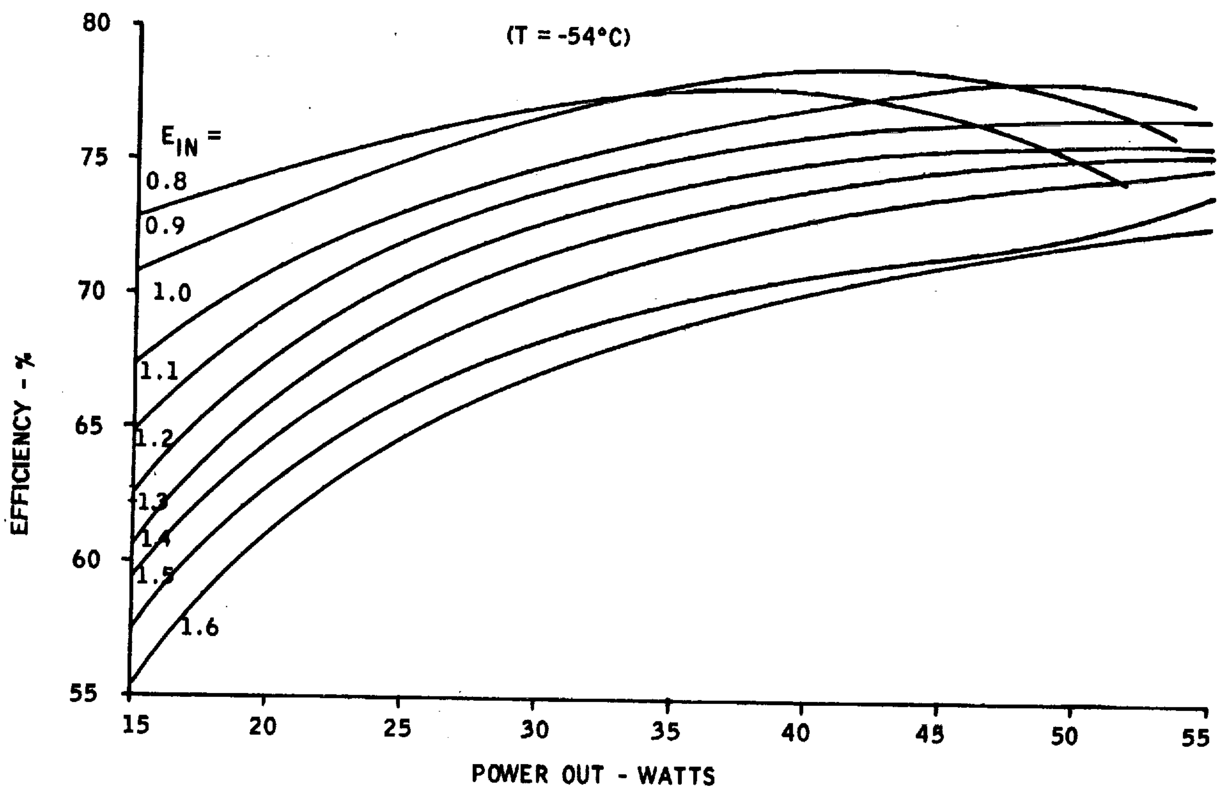


Figure 14 - MODEL PERFORMANCE WHEN OPERATING AT -54°C WITH INPUTS BETWEEN 0.8 AND 1.6 VOLTS

55 watts load indicate that the device would provide a considerably higher output power at slightly higher efficiencies.

The high temperature performance (70° C) of this converter is shown on Figure 15. The family of curves is similar to the curves obtained for the other ambient conditions. However, the overall efficiencies of the entire family of curves are slightly lower and we do notice a greater tendency for the efficiency curves to droop with low input voltages such as 0.8 and 0.9 volt at the heavier loads. Thus curves for 0.8 and 0.9 volt inputs show a decline in efficiency above 35 watts. An increase in the converter bus bar and winding resistance probably causes this increased droop. This effect is more noticeable at the lower input voltages because the input currents are considerably higher. Lower efficiency is primarily caused by increased conductor resistance and possibly by a change in the transistor parameters. Note that the efficiency is above the 70% design goal at 50 watts load for input voltages between 1 volt and 1.3 volts. For higher input voltages the 70% efficiency is achieved at heavier loads.

Heavy load performance curves for the converter connected for an 0.8 volt input are shown for ambient temperatures of 25° C, -10° C, -54° C, and +70° C on Figures 16, 17, 18, and 19, respectively. The room temperature performance curve on Figure 16 shows that the efficiency had already started to droop at 50 watts load and declined to 63% efficiency at 60 watts load. For the higher input voltage, however, the curve showed an increase with load and the maximum efficiency was 71.5% at 90 watts load. Figure 17 shows that the performance was slightly better at -10° C and that the maximum efficiency was nearly 80% at approximately 52 watts load. This efficiency declined rapidly to 70% at 60 watts load. The 1.6 volt curve, however, tended to show that the circuit could accommodate a much heavier load and the efficiency increased from 70% at 45 watts load up to 73.2% at 93 watts load. Figure 18 shows that the efficiency was slightly lower for 0.8 volt

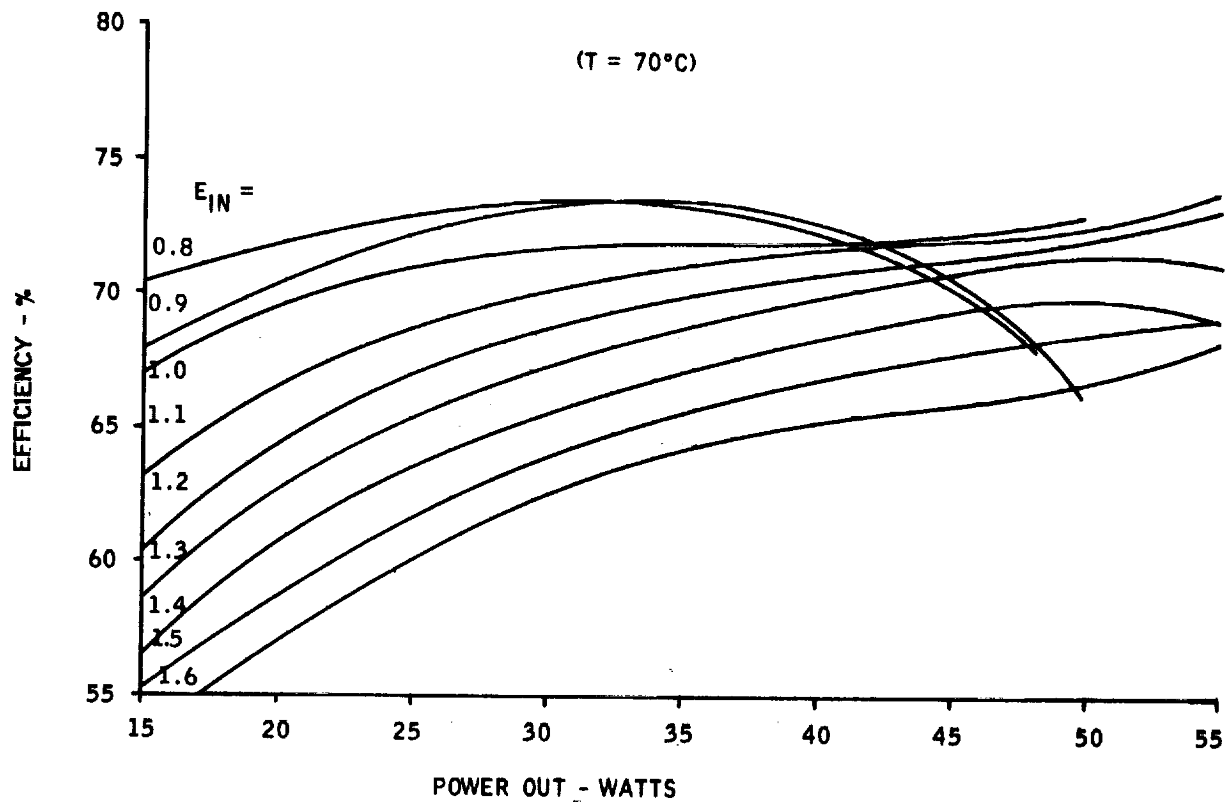


Figure 15 - MODEL PERFORMANCE AT 70°C WITH INPUTS BETWEEN 0.8 and 1.6 VOLTS

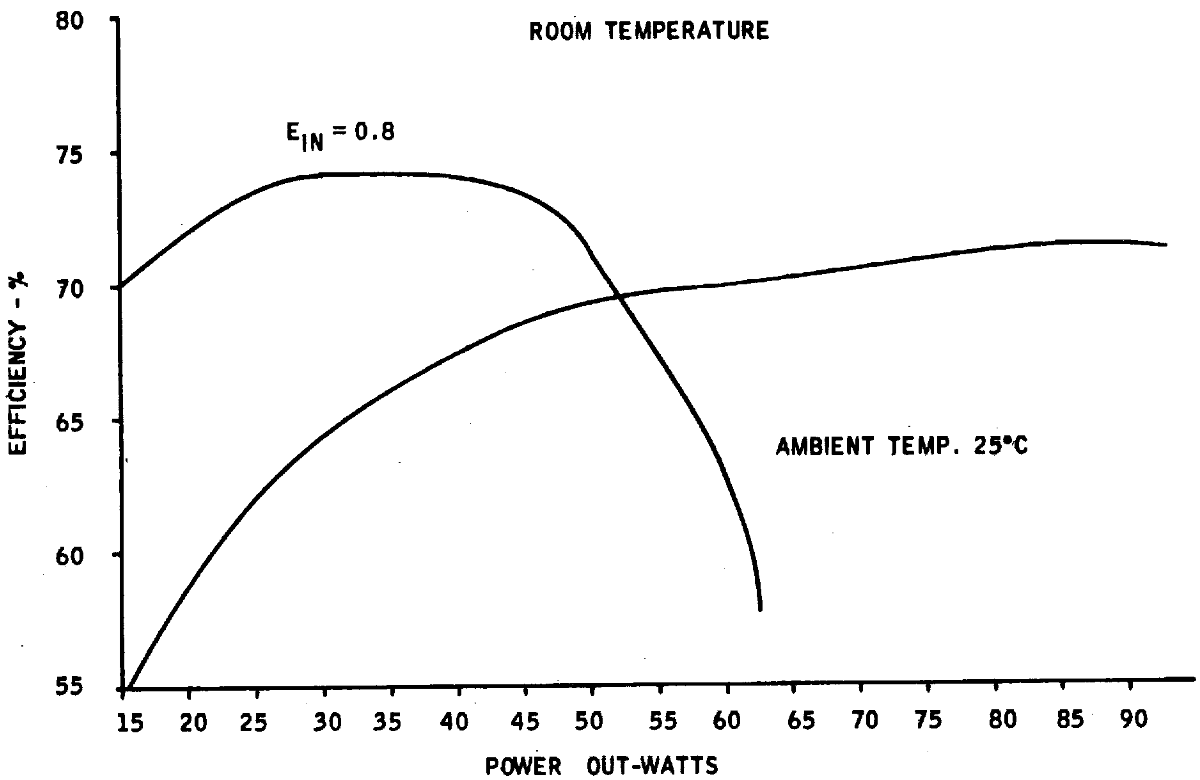


Figure 16 - HEAVY LOAD PERFORMANCE CURVES WHEN OPERATING AT ROOM TEMPERATURE AND CONNECTED FOR THE 0.8 TO 1.6 INPUT VOLTAGE RANGE

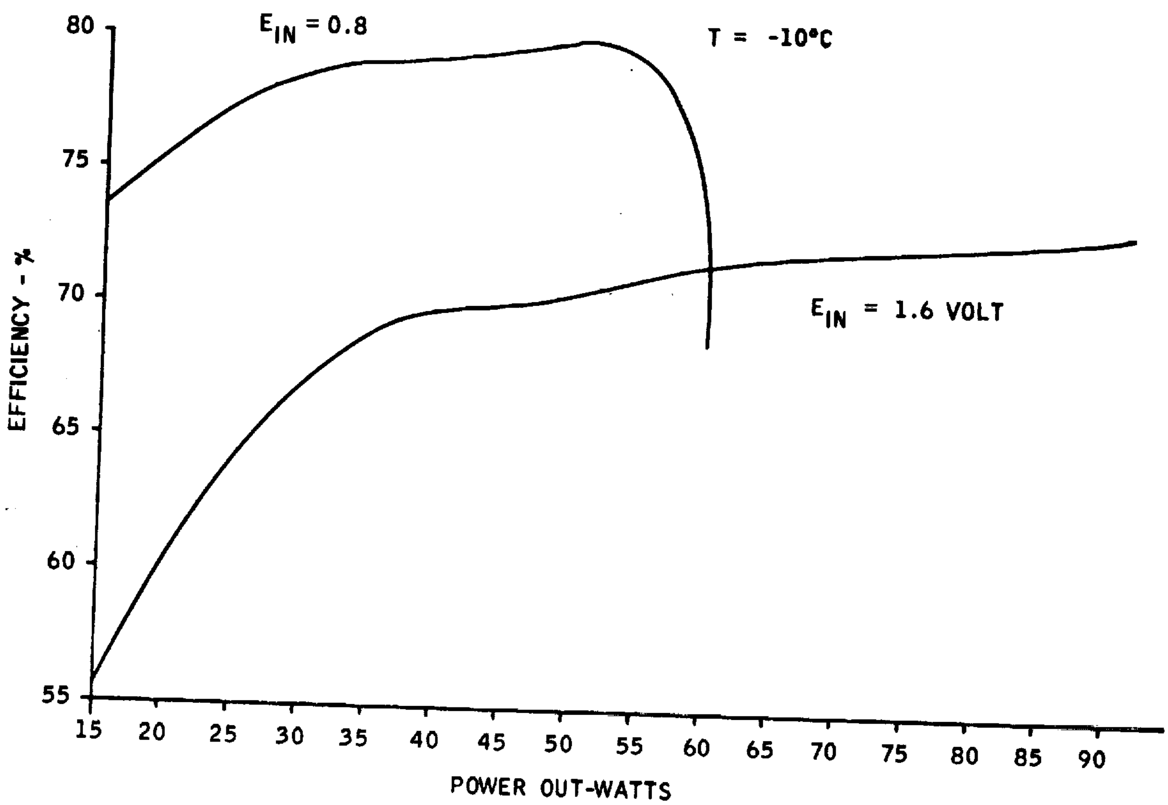


Figure 17 - HEAVY LOAD PERFORMANCE CURVES WHEN OPERATING AT -10°C AND CONNECTED FOR THE 0.8 TO 1.6 INPUT VOLTAGE RANGE

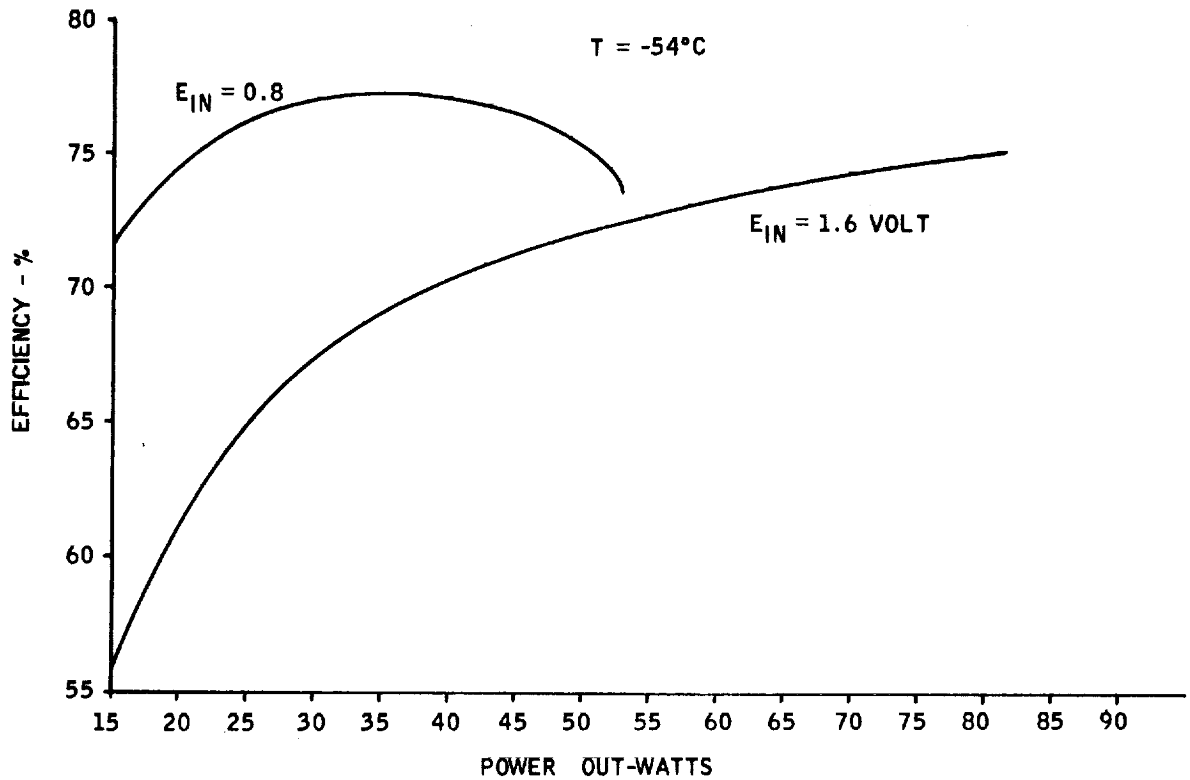


Figure 18 - HEAVY LOAD PERFORMANCE CURVES WHEN OPERATING AT -54°C AND CONNECTED FOR THE 0.8 TO 1.6 INPUT VOLTAGE RANGE

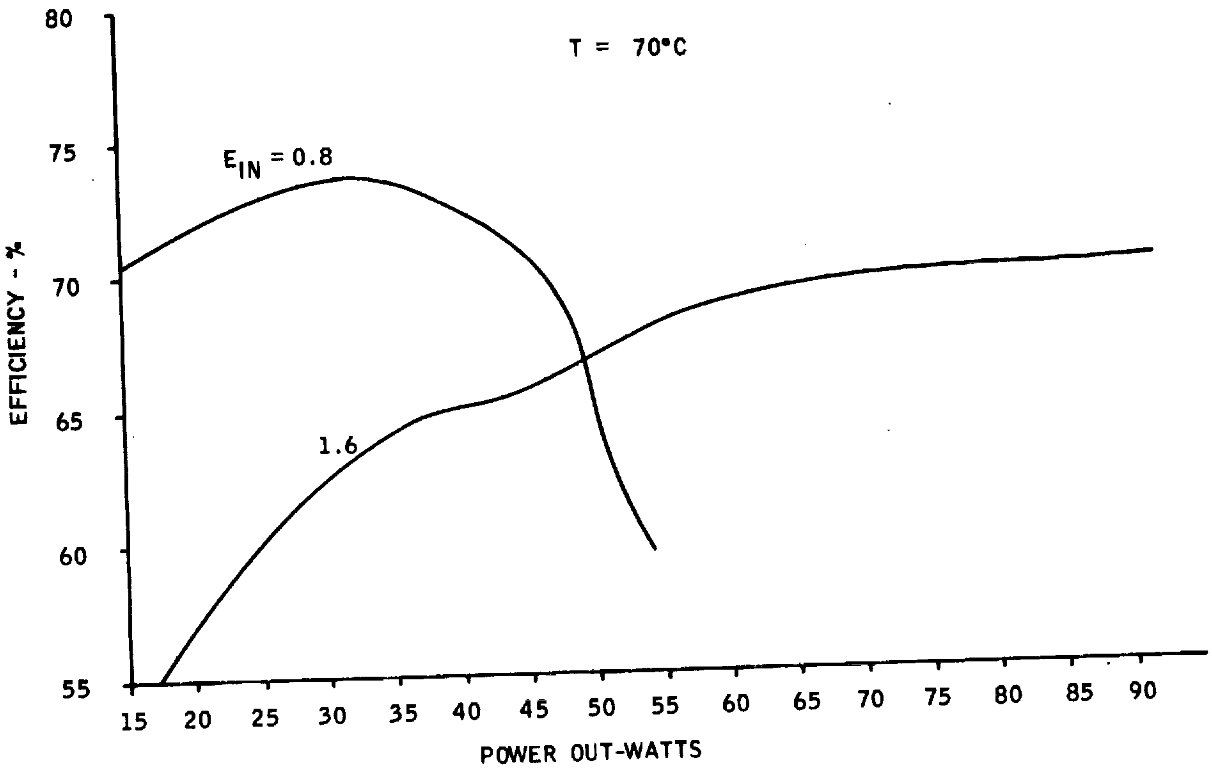


Figure 19 - HEAVY LOAD PERFORMANCE CURVES WHEN OPERATING AT 70°C AND CONNECTED FOR THE 0.8 TO 1.6 INPUT VOLTAGE RANGE

input. This efficiency tended to droop with load, declining to 73.5% at 53.5 watts load. Again, the 1.6 volt curve showed a smooth increase with load and 75.2% efficiency was obtained at 81.5 watts load.

The high temperature heavy load performance curve on Figure 19 shows that slightly lower overall efficiencies were obtained but the shape of the curves tended to be similar to the other curves. The 0.8 volt curve drooped at loads above 35 watts; the efficiency declined to 65% at 50 watts, and continued to decline to 60% at 53.5 watts load. The 1.6 volt curve, however, showed an increase in efficiency with increasing load out to a load of 92 watts. The efficiency was 70% at the 92 watt load.

The above performance curves showed that the converters operated satisfactorily over the input voltage, load, and ambient temperature ranges. The results also showed that much more than 50 watts could be drawn from the converter at higher input voltages. Depending on conditions, as much as 92 watts were drawn at 70% efficiency. In general, efficiencies are higher when the converter is operated over a more limited input voltage range near the design minimum.

## 2. Overload Protection Characteristics

The performance of the overload protection circuit was checked for the converter connected for minimum input voltages of both 0.8 volt and 1.2 volts. Overload characteristics were checked for the range having a 1.2 volt minimum at ambient temperatures of 25° C, -10° C, -54° C, and +70° C. These characteristics are shown on Figures 20, 21, 22, and 23, respectively. The overload protection characteristics are shown by a plot of output voltage versus output current. Room temperature characteristics are shown on Figure 20. Note that the regulated output voltage remained constant at 28 volts out to a load of 2.4 amperes for both the 1.2 and the 1.6 volt input. For the 1.2 volt input, the overload current limiting circuit initiated at a load of approximately

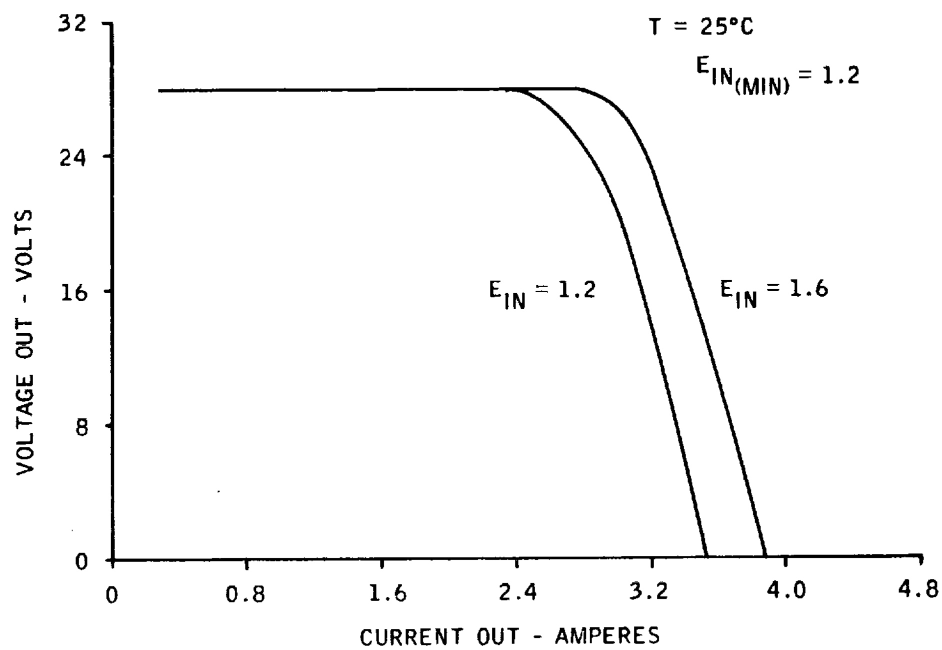


Figure 20 - ROOM TEMPERATURE OVERLOAD PROTECTION CHARACTERISTICS WHEN CONNECTED FOR A 1.2 TO 1.6 INPUT VOLTAGE RANGE

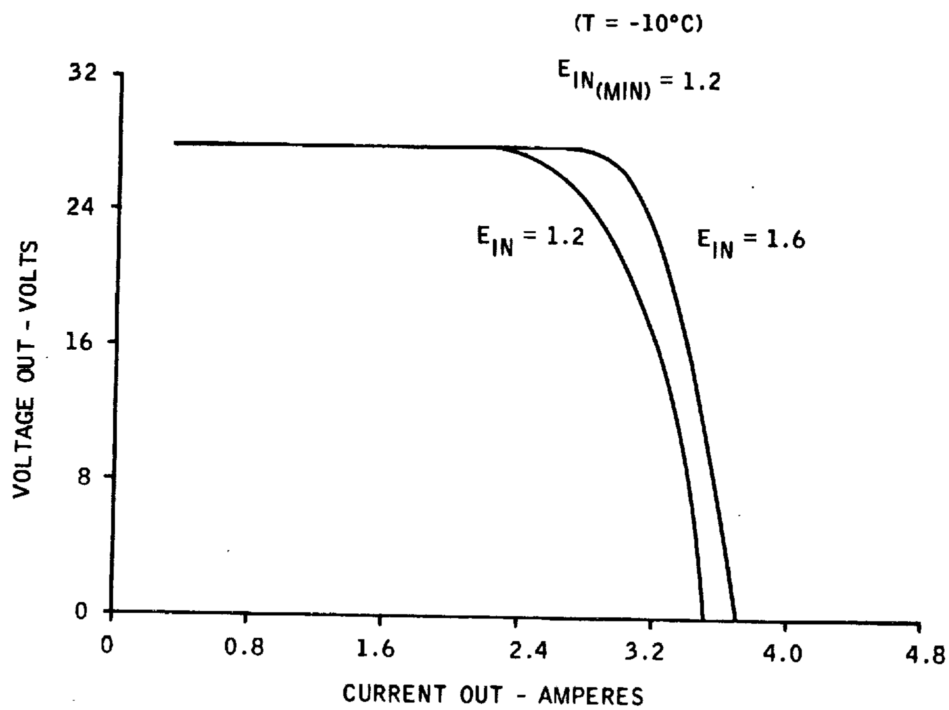


Figure 21 - OVERLOAD PROTECTION CHARACTERISTICS AT -10°C WHEN CONNECTED FOR THE 1.2 TO 1.6 INPUT VOLTAGE RANGE

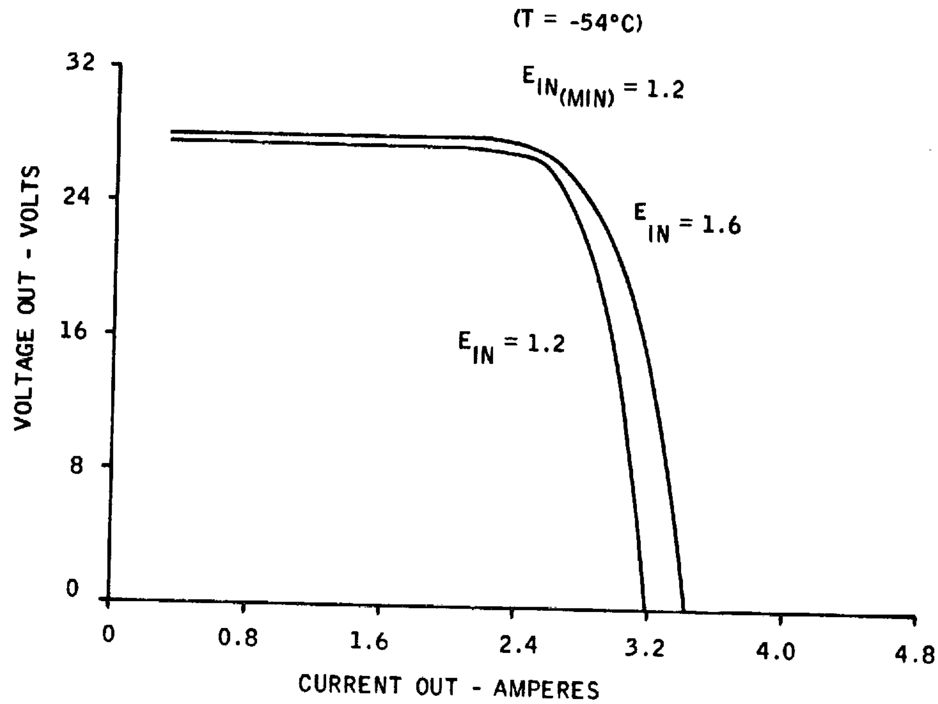


Figure 22 - OVERLOAD PROTECTION CHARACTERISTICS AT -54°C WHEN CONNECTED FOR THE 1.2 TO 1.6 INPUT VOLTAGE RANGE

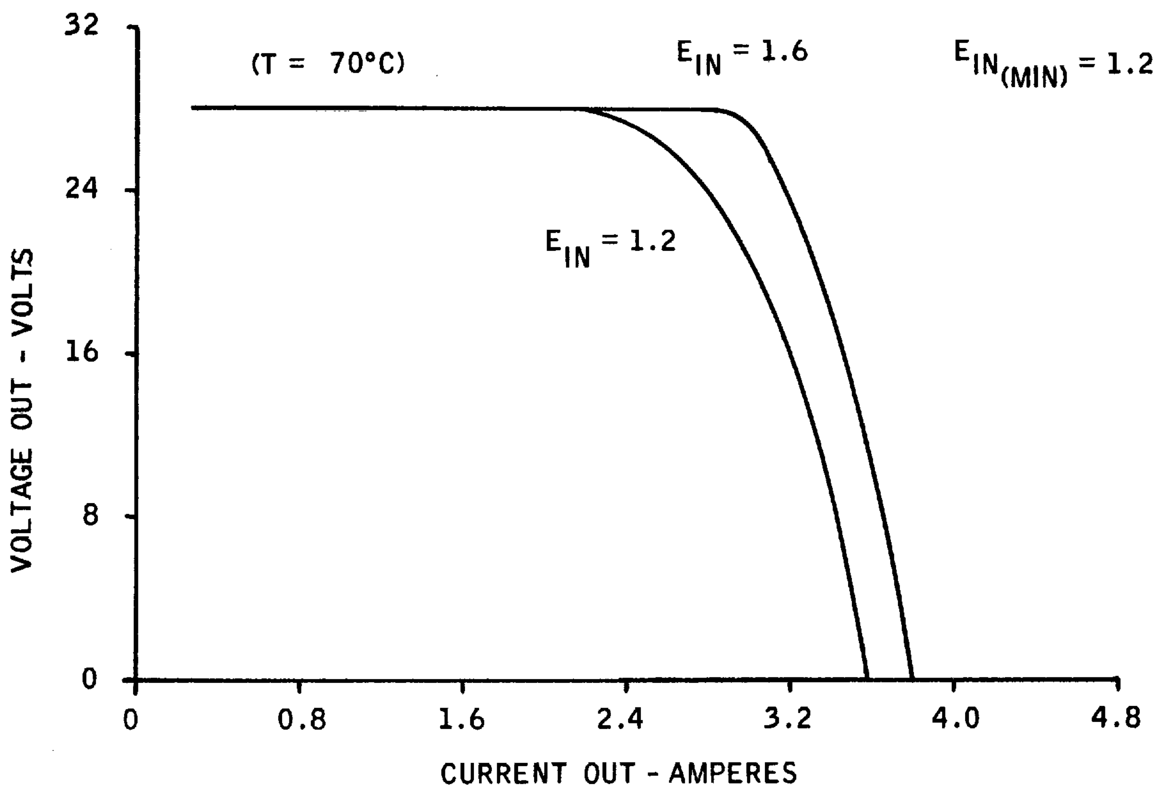


Figure 23 - OVERLOAD PROTECTION CHARACTERISTICS AT -54°C WHEN CONNECTED FOR THE 1.2 TO 1.6 INPUT VOLTAGE RANGE

2.5 amperes, and thereafter the voltage decreased rapidly as the load current was increased. At 3.2 amperes load the output voltage declined rapidly to 14 volts, and continued linearily to zero at a load of 3.55 amperes. With a 1.6 volt input, the output was regulated at 28 volts until the load current reached 2.8 amperes. As the load resistance was decreased below this point, the output voltage declined rapidly in a nearly linear manner to 3.9 amperes with zero output voltage (dead short). These characteristics show that the overload protection circuit limits the current to a safe value between 3.5 and 3.9 amperes when the output is shorted. Examination of the overload protection characteristics for operation at -10° C on Figure 21 shows that the characteristics were nearly identical to those obtained at room temperature. Variations in the initiating point of the current limiting circuit were very minute, and the short circuit current was held to between 3.5 and 3.7 amperes. The overload protection characteristics shown on Figure 22 for operation at -54° C are also similar to those described above. The output voltage was slightly low with a 1.2 volt input at -54° C, but the current limiting initiated at approximately 2.5 amperes and limited the short circuit current to between 3.2 and 3.4 amperes. Figure 23 shows the high temperature overload protection characteristics. Note that these are very similar to the characteristics obtained at the other temperatures. Current limiting was initiated between 2.3 and 2.9 amperes, and the overload current was limited to between 3.6 and 3.8 amperes at short circuit.

Examination of the above curves for the various ambient temperatues show that the overload protection characteristics were virtually independent of temperature and remained uniform and nearly linear throughout the operating range.

Overload protection characteristics for the converter connected for the lower 0.8 volt input are shown on Figures 24, 25, 26, and 27. Figures 24 shows that the output voltage tended to decline early with an 0.8 volt input. This slight

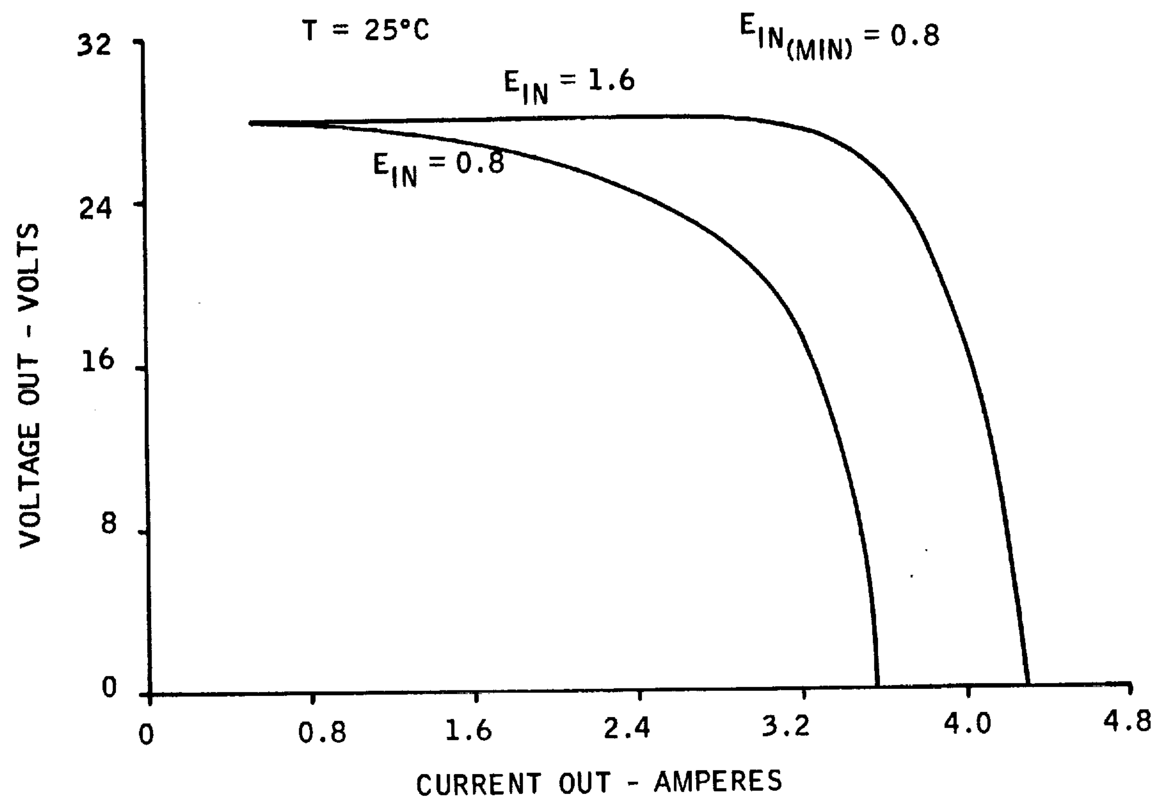


Figure 24 - OVERLOAD PROTECTION CHARACTERISTICS AT ROOM TEMPERATURE WHEN CONNECTED FOR THE 0.8 TO 1.4 INPUT VOLTAGE RANGE

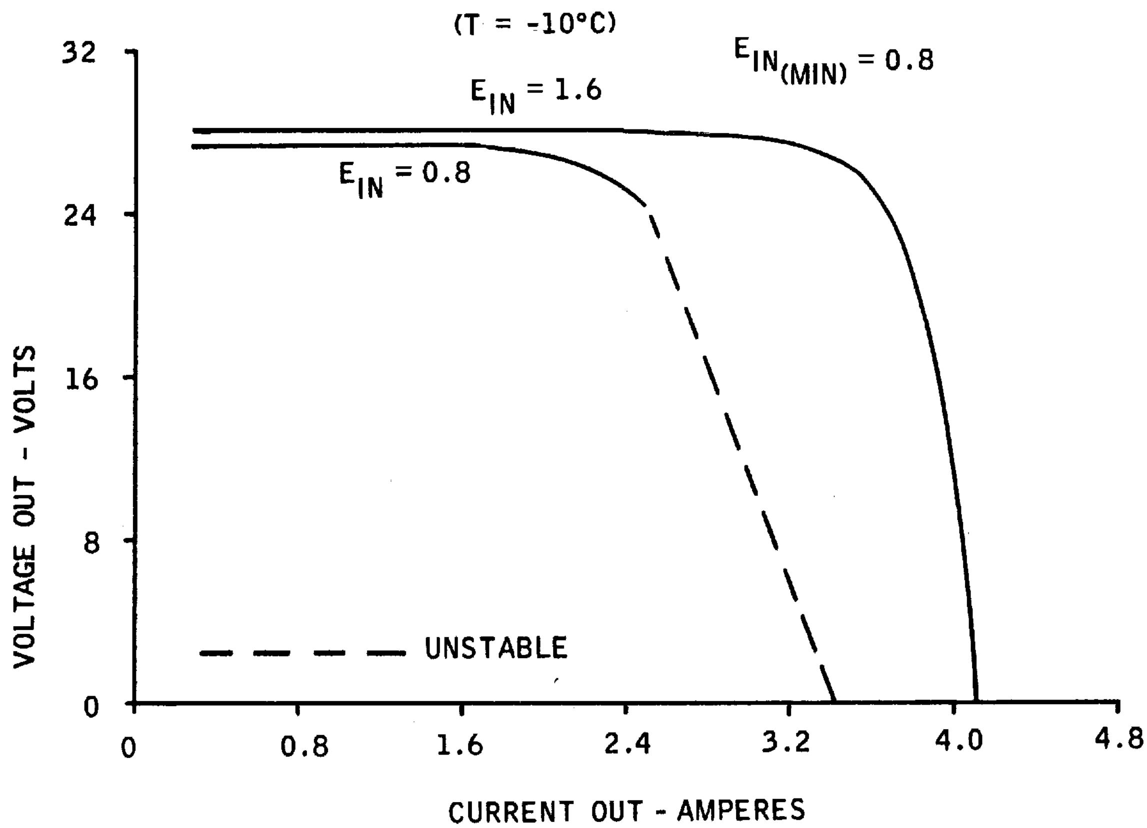


Figure 25 - OVERLOAD PROTECTION CHARACTERISTICS AT -10°C WHEN CONNECTED FOR THE 0.8 TO 1.6 INPUT VOLTAGE RANGE

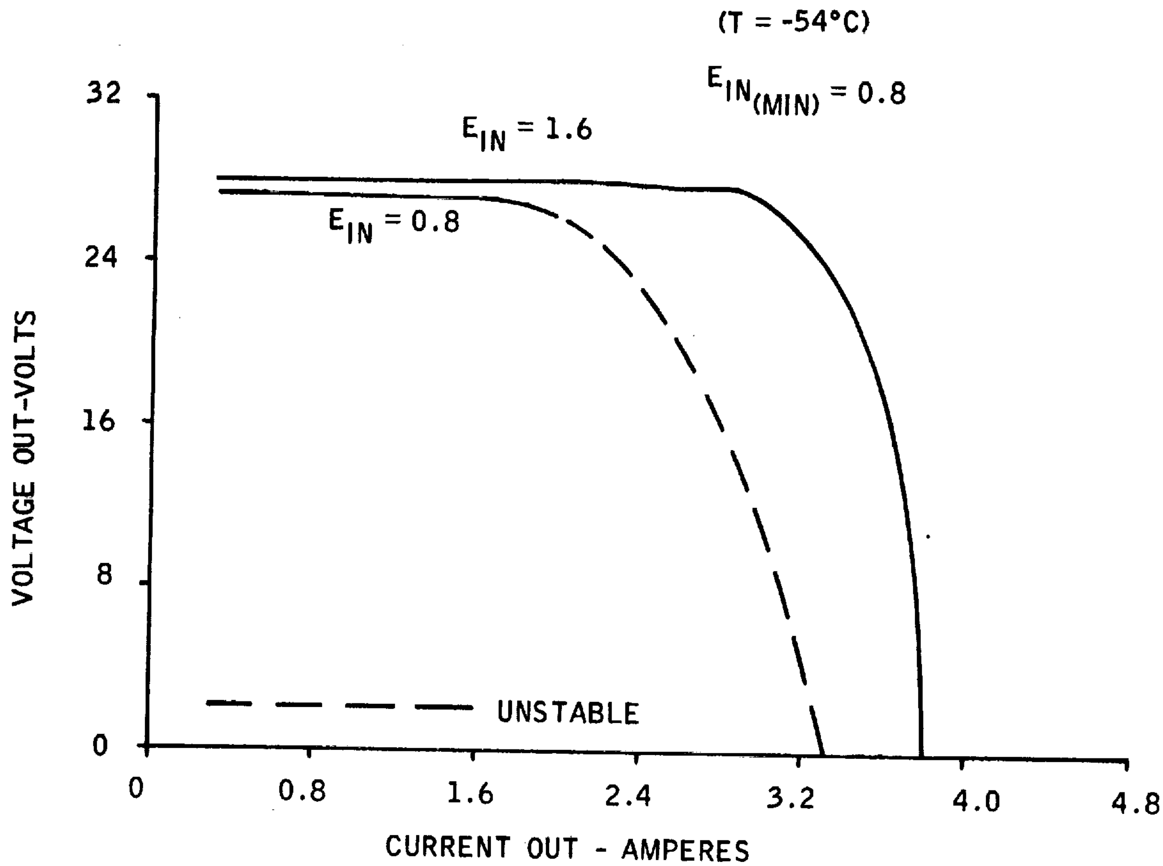


Figure 26 - OVERLOAD PROTECTION CHARACTERISTICS AT -54°C WHEN CONNECTED FOR THE 0.8 TO 1.6 INPUT VOLTAGE RANGE

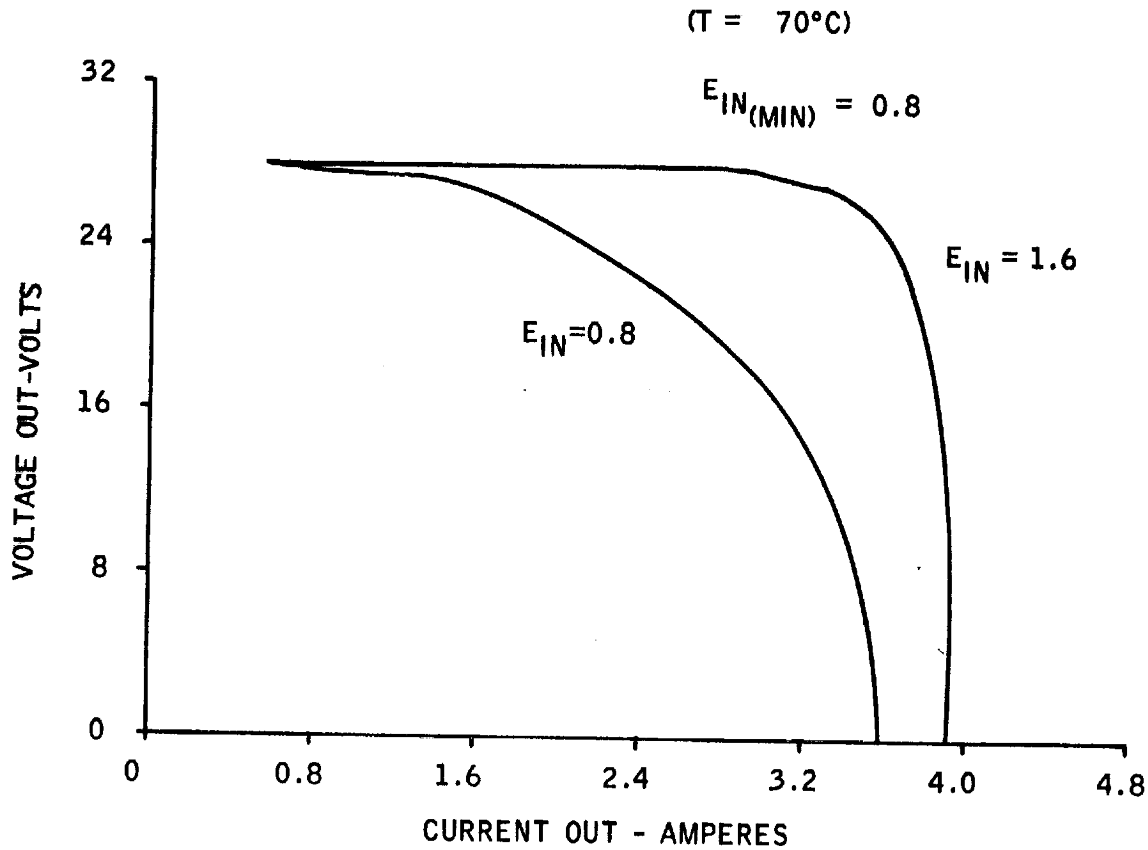


Figure 27 - OVERLOAD PROTECTION CHARACTERISTICS AT 70°C WHEN CONNECTED FOR THE 0.8 TO 1.6 INPUT VOLTAGE RANGE

early decline was due to the operation of the converter and voltage regulator, not to the operation of the current limiting circuit. Note that the output voltage tended to decline more rapidly at approximately 2.8 amperes load. This is the point at which the overload current limiting circuit was initiated. This circuit limited the short circuit current to 3.55 amperes. With the higher 1.6 volt input the output voltage was maintained at 28 volts up to a load of 2.9 amperes. At loads above this, the current limiting circuit initiated, reducing output voltage and limiting the short circuit current to 4.3 amperes.

The overload protection characteristics for operation at -10° C are also very similar. Figure 25 shows that for a 0.8 volt input the current limiting action initiated at a load of 2.5 amperes and it limited the short circuit current to 3.4 amperes. The overload protection circuit rapidly initiated, and readings between 2.5 amperes and 3.4 amperes could not be obtained. With a 1.6 volt input, the load current increased to 3.3 amperes before the overload protection circuit was initiated and the short circuit current was limited to 4.1 amperes.

Figure 26 shows the performance characteristics at -54° C. At this temperature, the heavy load output voltage drooped because the converter-regulator could not hold it up with a 0.8 volt input. The current limiting circuit appeared to initiate at approximately 2.0 amperes and limited the overload current to 3.3 amperes during short circuit. With a 1.6 volt input, the overload circuit initiated current limiting at approximately 2.8 amperes and limited the short circuit current to 3.8 amperes.

Figure 27 shows the high temperature overload characteristics. Again with the 0.8 volt input, the regulated output drooped at heavier loads. The point at which current limiting initiated is more difficult to determine. However, it appears that this was initiated at approximately 3 amperes, and the short circuit current was limited to 3.6 amperes. For the 1.6 volt input, the current limiting initiated at approximately 3.3 amperes and limited the short circuit current to 3.9 amperes.

Examination of the above overload protection characteristics shows that the overload protection circuit functioned for all input voltages over the ambient temperature range. The current limiting characteristics were quite sharp and would rapidly reduce the output voltage once the overload current set point was exceeded. For the very low 0. 8 volt input, however, the characteristics appeared less sharp. This rounding of the characteristics is caused by an input voltage too low to maintain the required regulated output at heavy load. Because of this droop at low input voltage the exact point at which the current limiting initiated could not be readily determined.

3. Voltage Regulation

The voltage regulation of this device is shown by the curves on Figures 20, 21, 22, and 23 for the converter connected to accommodate inputs between 1. 2 and 1. 6 volts. Additional data is shown on the data sheets in Appendix A. Figures 20 and 23 show that the output voltage was maintained constant at 28. 0 volts for inputs between 1. 2 and 1. 6 volts over the 0. 3 to 2. 0 ampere load range while operating at ambient temperatures of 25° C and +70° C, respectively. Figure 21 shows that the output voltage level declined to 27. 6 volts at the -10° C temperature for the 1. 2 volt input. Data sheets numbers 9, 10, and 11 in Appendix A show that the output was maintained above 27.8 volts for all inputs above 1. 2 volts at this temperature.

Figure 22 shows that the output voltage level declined to 27. 4 volts at -54° C with a 1. 2 volt input. However, the output was maintained at 28 volts with a 1. 6 volt input. Examination of the output voltage data on data sheets number 16, 17, and 18 provides further information which indicates that compensation for input voltage changes is imperfect at the -54° C temperature. Note that the curves are very flat; this indicates excellent regulation with load. The slight decline in output voltage at -54° C does not present a problem because this temperature is much lower than required. By properly adjusting the regulator set point, the output voltage can be maintained at 28. 0 ± 1% over the required -10° C to +70° C ambient temperature range.

The voltage regulation with the device connected for the 0.8 to 1.6 volt range is shown on Figures 24, 25, 26, and 27, for ambient temperatures of 25° C, -10° C, -54° C, and 70° C. These curves show that the output is regulated at 28.0 volts at all temperatures when the input voltage is 1.6 volts. However, the 0.8 volt curve shows a tendency to droop at heavier loads. The voltage level is also slightly low at the -10° C and -54° C temperatures. Further detail is shown on data sheets numbered 20, through 39 in Appendix A. Examination of this data indicates that the output voltage droops at heavy load with the 0.8 volt input because the regulator is operating near its threshold value and has lower gain in this region. When the input voltage is raised to 0.9 volt, the output voltage remains flat because the input to the voltage regulator is high enough to maintain the required output and the regulator operates above its threshold value. The performance data indicates that the regulator operates well over the 0.9 volt to 1.6 volt range. We do note a slight decrease in voltage with low inputs at low temperature and an increase in output to 28.4 volts at 70° C with higher input voltages. This indicates that the compensation for input voltage changes at lower temperature could be improved. The voltage rise at high temperature indicates that stabilization current through resistors R8 and R9 should be increased. The output voltage may rise with higher inputs when the device is connected for a minimum of 0.8 volts and operated at 70° C because the input voltage to the regulator is about 56 volts. The high input voltage and high temperature increases the transistor leakage current. This effect is minimized by the stabilizing back bias current flow through R8 and R9. The test data shows that under these conditions, the back bias current should have been higher. This effect could also be minimized by using the silicon chopping transistor as indicated in Progress Report II.

The performance data described above shows that the converter regulator maintained very tight regulation over wide variations in load, input voltage, and ambient temperature. In general, the performance meets the design goals. Some improvement could be made by adjusting the set point and increasing the compensation for input voltage variations. Tighter regulation results when the range of input voltage variation is decreased.

4. Output Ripple

Test report OEXM 10610 performance data in Appendix A shows that the output ripple tends to increase with load and with input voltage. The increase with load is a normal relation between the energy stored in the filter circuit and the rate of energy flow. The increase in ripple with input voltage is caused by a lower conduction duty cycle of the regulator pulse modulating transistor. Data sheet #3 in OEXM 10610 shows that the maximum peak to peak ripple was 100 millivolts when the input voltage was 1. 2 volts and the transformer taps were connected for a minimum input voltage of 1. 2 volts. Data sheets 3, 4, and 5 show that the maximum peak to peak ripple rose to 140, 180, 200, and 230 millivolts when the input voltage was increased to 1. 3, 1. 4, 1. 5, and 1. 6 volts, respectively. Data sheets 24, 25, and 26 show that the converter with the transformer connected for a 0. 8 volt minimum input had maximum peak to peak ripple of 100, 165, 225, 270, and 320 millivolts for input voltages of 0. 8, 0. 9, 1. 0, 1. 1, and 1. 2 volts, respectively. At higher input voltages the ripple increased, reaching 410 millivolts at 50 watts load with a 1. 6 volt input.

Data sheets 20, 21, 22, 23, and 24 indicate that the peak to peak output ripple declines at the higher 70° C temperature. Data sheets 29, 30, 31, 32, and 33 show that the output ripple increases considerably at the -65° F (-54° C) temperature. This change in ripple is caused primarily by parameter changes in the tantalum filter capacitors. Performance at the lower specification temperature limit, -10° C, is shown on data sheets 34, 35, 36, 37, and 38. This shows a considerable increase in ripple over the room temperature readings and is within ± 2% peak to peak, for inputs between 0. 8 and 1. 5 volts. This exceeds the 1% peak-to-peak ripple maximum limit. Therefore, the pulse width modulation regulator should be operated at a higher frequency to reduce the ripple to the specification limit.

The measurements described above show that the ripple increases with load and with input voltage. The increase in ripple with input voltage is due to a reduction in the conduction duty cycle of the pulse modulating regulator. These results show that the size of the filter should be larger for converters designed to operate from sources having wider input voltage variations. The data also shows that the ripple increases at lower temperature due to a decline in filter capacitance at low ambient temperature. When the unit was connected for a minimum input voltage of 1.2 volts, the output ripple was within the 1% peak-to-peak design goal for all loads and inputs between 1.2 and 1.6 volts over the -10° C to +70° C temperature range, with the exception of the 1.5 and 1.6 volt inputs at -10° C. At this temperature, the maximum ripple was 350 millivolts peak to peak at 55 watts load with a 1.6 volt input.

Examination of the above ripple measurements shows that the output ripple is generally below the 280 millivolt peak-to-peak design goal, but it does creep outside this limit at higher input voltages at low temperature. To meet the design goal under all environmental conditions it will be necessary either to increase the size of the filter, or use capacitors with a lower temperature coefficient, or operate the regulator at a higher frequency. The latter approach appears the most promising.

## F. RELIABILITY ESTIMATE

To provide reliability estimates for the low input voltage converter-regulators some reliability calculations have been made on the converter model fabricated under this program. This information will be useful in comparing the reliability of source-converter power systems with the alternative series or series-parallel source combinations required to achieve a useful operating voltage. Reliability information of this type will enable the system designer to determine the reliability "trade-offs" for various systems configurations. The reliability data is shown in Appendix B. Calculations were made on the circuit for two operating temperatures and for two types of components. The estimated "Mean Time Between Failure" for the Basic Converter, the regulator, and the entire device is shown below:

| | Std. Military Parts | | Minuteman Parts | |
|---|---|---|---|---|
| | 25° C | 50° C | 25° C | 50° C |
| Regulator | 75, 400 hrs | 56, 600 hrs | 787, 000 hrs | 657, 000 hrs |
| Basic Converter | 98, 500 hrs | 82, 400 hrs | 998, 000 hrs | 907, 400 hrs |
| Entire Device | 42, 700 hrs | 33, 500 hrs | 438, 000 hrs | 381, 000 hrs |

The achievement of the indicated reliability estimates is dependent upon an active reliability program as well as qualification of the Honeywell transistors to the applicable military and space requirements.

The high calculated reliabilities allows us to conclude that the incorporation of low input voltage converters with the new energy sources provides an excellent opportunity to improve greatly the overall reliability of future space power systems.

## SECTION V

## CONCLUSIONS

From the results obtained during this program, we can conclude that the transistor low input voltage converter-regulator is a feasible method of converting the low output voltages of the new energy sources to a higher more useable regulated voltage for use in space power systems. Performance measurements have shown that current feedback transistor power oscillators achieve the required high efficiencies and that they operate well from:

a. low voltage sources,

b. varying voltage sources,

c. operate efficiently over a wide load range,

d. operate efficiently over temperature ranges between -54° C and 70° C.

The current feedback converter is designed to operate efficiently with all of the above parameter variations and is also designed to operate efficiently even if the transistor parameters (such as input impedance and gain change) during the operating mission. Efficient operation of the converter is achieved because optimum current feedback drive is furnished to the power amplifier transistors for all conditions of load, input voltage, and transistor input impedance.

With low input voltages, the input current is very high in relationship to the power converted. The transistor drive required is a function of the transistor collector current. Therefore, the transistor drive is an appreciable portion of the power handled by a low input voltage converter. The current feedback converter circuit provides maximum efficiency by optimizing drive for all load conditions regardless of input voltage and temperature changes. The circuitry and transformer connections used, provide a considerable amount of overdrive with a minimum of power dissipation to guarantee efficient transistor operation in the very low saturation region when the current gain varies from transistor to transistor, over the temperature range, or with aging. Investigation of the transistor voltage regulator showed that the best approach for this application was an "add-on" type pulse width modulation regulator. One of the main reasons for this is that the low input voltage converter and the voltage regulator can be isolated from each other by means of a capacitor filter between the converter and the voltage regulator. This filter prevents pulse width modulation effects of the regulator from being fed back to the low input voltage converter section. This also prevents pulse modulation of the oscillator current and minimizes ripple feedback into the power source. This may be important when operating from some of the new energy sources. Elimination of pulse width modulation effects in the power converter improve efficiency because the oscillator transistors and transformer windings conduct uniform-rated load currents throughout each entire half cycle. If the converter currents were pulsed, the resulting peak currents would increase the losses. The overall efficiency of the voltage regulator utilized with this converter varies between 87 and 94% depending upon the input voltage and load conditions for the particular measurements under consideration.

Investigation of frequency control and synchronization showed that it was unnecessary to synchronize the basic power oscillator with the voltage regulator. Experiments showed that it was desirable to allow the power oscillator frequency to vary directly proportional to input voltage. This maintained the transformer maximum operating flux density nearly constant and diminished a tendency of the output transformer to saturate toward the end of one-half cycle. A choke coil connected from base to base in the current feedback power oscillator is desirable to achieve more overdrive during switching and to minimize the tendency to pause at one side of the hysteresis loop during the switching interval.

Performance results obtained on the model fabricated and shipped to the NASA-Goddard Space Flight Center showed that the performance and efficiency requirements of the converter were met. Performance tests showed that the overall efficiency exceeded the design goal of 70% and even tended to exceed a 75% efficiency figure for most of the operating conditions at 50 watts load. This converter maintained a high efficiency over a wide input voltage, load, and ambient temperature range. The results showed that considerably more than 50 watts could be drawn from this regulated converter at high efficiency for all but the very low input voltages. For some of the higher input voltages, the converter achieves maximum efficiencies with loads between 70 and 90 watts. Measurements show that the converter operates at high efficiencies even with a 2 to 1 input voltage swing between 0.8 and 1.6 volts. However, higher efficiencies are obtained if transformer connnections are used for the more limited input range of 1.2 to 1.6 volts. Higher efficiencies are obtained for input voltage variations between 0.8 and 1.2 volts than above 1.2 volts when the converter is connected for the 0.8 to 1.6 volt range. Conversely, lower efficiencies are obtained at high voltage when the converter is designed to accommodate the lower 0.8 volt input because the higher input voltages reduce the pulse width modulation regulator conduction duty cycle. Therefore, it must conduct the power in a shorter period, increasing the $I^2R$ and other circuit losses. Performance data on this unit proves that it operates well over the input voltage, load, and ambient temperature range. The design requirements are exceeded by a considerable amount for most of the above operating conditions.

An overload protection circuit incorporated into the voltage regulator protects the circuit from all overloads and current surges. The current limiting circuit will continually sense and limit the overload; however, when the overload is removed, the circuit will immediately furnish the required power to the load. Circuit investigation showed that it is necessary to sense the overload current directly at the output. It is also necessary to protect the transistor from the discharge of one filter capacitor into the other filter capacitor when the overload is suddenly removed. The present overload protection circuit performs these functions.

Ambient temperature tests showed that the voltage regulator maintained the output voltage at 28 volts ± 1% over the ambient temperature and load range except for some voltage regulator droop at the lower input voltage of 0.8 volt at heavy load. Tests at much lower temperatures than required showed satisfactory performance and proved that the device has a large margin of safety at the low temperature limit.

The weight of this converter model was 6-1/4 pounds and the size was 140 cubic inches. This exceeded the design goal of a 4-pound weight and a size of 120 cubic inches. However, the regulated converter would also supply a much higher output power than the required 50 watts at the higher input voltages. Thus it would be possible to reduce the converter weight and size to the specification requirements if the range of input voltage variation were more limited.

It can be concluded from the measured performance data that the transistor low input voltage converter circuitry developed during this program has the performance characteristics necessary to convert the low voltage power of the new energy sources up to a useful level at high efficiency. Emphasis should now be placed upon incorporation of this technology into practical systems.

## SECTION VI

## RECOMMENDATIONS

This investigation has established that the transistor low input voltage convertion approach is practical and feasible. Further work should now be directed towards the design of energy conversion source - low input voltage converter-regulators for incorporation into practical and reliable space power systems. To accomplish this the following should be emphasised:

a. Investigate the performance of low input voltage converter regulators when operating from specific sources.

b. Direct effort toward a reduction in switching losses to facilitate operation at higher frequency to reduce weight.

c. Examine the "trade-off" between source weight, converter weight, converter efficiency, and source voltage variations.

d. Determine optimum converter design to minimize external magnetic field disturbance and radio noise interference.

e. Examine package design for specific applications to ensure adequate heat transfer, minimum electromagnetic disturbance, and minimum weight to withstand specific space environments.

f. Conduct reliability calculations on specific source-converter-regulator systems to determine reliability "trade-off" for various system configurations.

Further work in the above areas should lead to the development of improved space power systems which will provide the necessary regulated system voltages at a much higher reliability than can be obtained with present series-parallel configurations.

Prepared by John T. Lingle

John T. Lingle
Project Engineer

Approved by H T Mooers

H. T. Mooers
Project Supervisor

# APPENDIX A

## ENGINEERING TEST REPORT

## OEXM 10610

Military Products Group

REPORT NO. OEXM 10610

DEV. NO. G* 4016-A01

# ENGINEERING TEST REPORT

DATE 4-3-64

PAGE ____ OF ____

ISSUED BY: ORDNANCE EVALUATION ENGINEERING

COPY LIST:

KEYWORDS:

ATTACHMENTS:

## UNIT TESTED:

One (1) Low Input Voltage Converter, S/N 1, EXG2424D1X1, 50 watt - 1.2 VDC Model, manufactured by M-H Ordnance Tech Lab.

## OBJECT OF TEST:

Measure and record input voltage, input current, output current, output voltage, operating frequency, output ripple voltage, and collector to emitter saturation voltage, at 1.2, 1.3, 1.4, 1.5 and 1.6 volts DC input over the range of 15 to 50 watts output. Calculate the input power, output power and the overall efficiency. Draw curves to display efficiency, overload protection, and extended power characteristics. The tests are to be conducted at room temperature 158°F, 14°F and -65°F. Repeat the above with the unit adjusted to operate at a minimum of 0.8 volts DC input with input voltages from 0.8 to 1.6, in 0.1 volt steps.

## DOCUMENTATION:

The table on page 2 shows the limitations of the converter under the conditions described in the object. See the attached graphs and data sheets for the detailed results.

| DATA BOOK NO. | PAGE | | |
|---|---|---|---|
| 846 | 27 | | |
| REQUESTED BY | DATE | WRITTEN BY | |
| John T. Lingle | 3-27-64 | [signature] | |
| DEPARTMENT | | APPROVED | |
| Electromechanical-Engineering | | [signature] | |

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IPG-1046 WHITE
IS-1046A DITTO MASTER

$E_{in(min)} = 1.2$

| Temperature °F | Efficiency % | | Ripple Voltage Peak to Peak MV | | Frequency cps | | Maximum Output Current Amperes |
|---|---|---|---|---|---|---|---|
| | Max | Min | Max | Min | Max | Min | |
| Room | 78.5 | 66.2 | 230 | 84 | 585 | 436 | 3.9 |
| 158 | 76.4 | 62.1 | 210 | 60 | 597 | 411 | 3.8 |
| 14 | 79.0 | 61.9 | 350 | 125 | 587 | 436 | 3.7 |
| -65 | 78.6 | 60.5 | 880 | 290 | 615 | 411 | 3.4 |

$E_{in(min)} = 0.8$

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Room | 74.6 | 54.1 | 420 | 80 | 860 | 405 | 4.3 |
| 158 | 74.2 | 55.4 | 325 | 60 | 889 | 425 | 4.1 |
| 14 | 79.1 | 55.5 | 630 | 120 | 870 | 426 | 4.1 |
| -65 | 78.7 | 55.7 | 1650 | 230 | 849 | 421 | 3.8 |

**PROCEDURE:**

The Low Input Voltage Converter was placed in an environmental chamber and connected to a low voltage power supply. The input and output voltages and currents were monitored with laboratory type instruments. The output ripple voltages were monitored with an oscilloscope. The operating frequencies were monitored with an electronic counter.

**RESULTS:**

See attached data sheets.

**INSTRUMENTATION:**

| Instrument | Model | M-H No. | Use |
|---|---|---|---|
| Counter | C.M.C. 726B | 114-024 | Frequency |
| Oscilloscope | Tek 503 | 138-034 | Ripple Voltage |
| DC Ammeter | Weston 45 | 102-005 | Input Current |
| DC Ammeter | Weston 45 | 102-007 | Output Current |
| Shunt | 5 Ampere | 102-036 | Output Current |
| Shunt | 200 Ampere | 102-059 | Input Current |
| Shunt | 100 Ampere | 102-042 | Input Current |
| Slidewire | 54 ohm, 3.3A | 144-032 | Load |
| Slidewire | 10.1 ohm, 8.5A | 144-023 | Load |
| DC Voltmeter | Weston 931 | 158-006 | Output Voltage |
| Variac | 18 Amp | 501-002 | Input Voltage Control |
| Transformer | Stancor P-6161 | 152-059 | Oscilloscope Isolation |
| DC Voltmeter | Fluke 801 | 162-004 | Input Voltage |
| Temperature Chamber | 2H | 340-003 | Temperature Tests |

OEXM 10610
DATE 3-25-64

# LIV Converter
## EXG 2424
## 50 Watt

$E_{in(min)} = 1.2$

$E_{in}$ 1.2 VDC  Temperature RM °F (25°C)

| $I_{in}$ Amp | $E_{out}$ Volt | $I_{out}$ Amp | Freq CPS | Ripple P-P MV | $P_{in}$ Watt | $P_{out}$ Watt | EFF % | $V_{CE}$ (sat) M Volt |
|---|---|---|---|---|---|---|---|---|
| 18.3 | 28 | 0.535 | 436 | 90 | 22.0 | .15 | 68.0 | 38 |
| 23.1 | | 0.715 | 435 | 84 | 27.7 | 20 | 72.0 | |
| 28.2 | | 0.890 | 433 | 95 | 33.8 | 25 | 74.0 | |
| 33.1 | | 1.070 | 429 | 96 | 39.8 | 30 | 75.5 | 45 |
| 38.2 | | 1.250 | 427 | 96 | 46.0 | 35 | 76.0 | |
| 43.2 | | 1.430 | 424 | 100 | 51.9 | 40 | 77.2 | |
| 48.9 | | 1.610 | 420 | 96 | 58.8 | 45 | 77.3 | 50 |
| 53.8 | | 1.790 | 413 | 90 | 64.5 | 50 | 77.5 | |
| 55.5 | | 1.960 | 415 | 95 | 70.0 | 55 | 78.5 | |

$E_{in}$ 1.3 VDC  Temperature RM °F

| $I_{in}$ Amp | $E_{out}$ Volt | $I_{out}$ Amp | Freq CPS | Ripple P-P MV | $P_{in}$ Watt | $P_{out}$ Watt | EFF % | $V_{CE}$ (sat) M Volt |
|---|---|---|---|---|---|---|---|---|
| 17.4 | 28 | 0.535 | 475 | 116 | 22.6 | 15 | 66.4 | 37 |
| 22.0 | | 0.715 | 470 | 120 | 28.6 | 20 | 70.0 | |
| 26.4 | | 0.890 | 468 | 120 | 34.3 | 25 | 73.0 | |
| 31.0 | | 1.070 | 466 | 120 | 40 3 | 30 | 74.5 | 44 |
| 36.0 | | 1.250 | 461 | 116 | 46.8 | 35 | 75.0 | |
| 40.9 | | 1.430 | 459 | 120 | 53.1 | 40 | 75.5 | |
| 45.2 | | 1.610 | 456 | 128 | 58.7 | 45 | 76.8 | 48 |
| 50.0 | | 1.790 | 455 | 124 | 65.0 | 50 | 77.0 | |
| 54.7 | | 1.960 | 450 | 140 | 71.0 | 55 | 77.5 | |

OEXM 10610
DATE 3-25-64

LIV Converter
EXG 2424
50 Watt
$E_{in\,(min)} = 1.2$

$E_{in}$ 1.4 VDC  Temperature RM °F (25°C)

| $I_{in}$ Amp | $E_{out}$ Volt | $I_{out}$ Amp | Freq CPS | Ripple P-P MV | $P_{in}$ Watt | $P_{out}$ Watt | EFF % | $V_{CE}$ (sat) M Volt |
|---|---|---|---|---|---|---|---|---|
| 16.2 | 28 | 0.535 | 511 | 148 | 22.7 | 15 | 66.2 | 36 |
| 20.9 | | 0.715 | 507 | 156 | 29.2 | 20 | 68.5 | |
| 24.8 | | 0.89 | 505 | 160 | 34.7 | 25 | 72.0 | |
| 29.0 | | 1.07 | 502 | 160 | 40.6 | 30 | 74.0 | 43 |
| 33.6 | | 1.25 | 492 | 170 | 47.0 | 35 | 74.5 | |
| 38.0 | | 1.43 | 496 | 170 | 53.1 | 40 | 75.4 | |
| 42.2 | | 1.61 | 491 | 170 | 59.0 | 45 | 76.0 | 47 |
| 46.7 | | 1.79 | 488 | 175 | 65.3 | 50 | 76.8 | |
| 51 | | 1.96 | 489 | 180 | 71.4 | 55 | 77.2 | |

$E_{in}$ 1.5 VDC  Temperature RM °F

| $I_{in}$ Amp | $E_{out}$ Volt | $I_{out}$ Amp | Freq CPS | Ripple P-P MV | $P_{in}$ Watt | $P_{out}$ Watt | EFF % | $V_{CE}$ (sat) M Volt |
|---|---|---|---|---|---|---|---|---|
| 15.8 | 28 | 0.535 | 547 | 170 | 23.7 | 15 | 64.4 | 36 |
| 19.9 | | 0.715 | 541 | 170 | 29.9 | 20 | 67.0 | |
| 23.8 | | 0.89 | 540 | 170 | 35.7 | 25 | 70.0 | |
| 27.5 | | 1.07 | 539 | 175 | 41.3 | 30 | 72.8 | 42 |
| 31.8 | | 1.25 | 535 | 175 | 47.7 | 35 | 73.4 | |
| 35.9 | | 1.43 | 531 | 180 | 53.9 | 40 | 74.4 | |
| 40.0 | | 1.61 | 529 | 180 | 60.0 | 45 | 75.0 | 46 |
| 44.0 | | 1.79 | 528 | 190 | 66.0 | 50 | 75.8 | |
| 48.2 | | 1.96 | 520 | 200 | 72.2 | 55 | 76.2 | |

OEXM 10610
DATE 3-25-64

LIV Converter
EXG 2424
50 Watt

$E_{in(min)} = 1.2$

$E_{in}$ 1.6 VDC Temperature RM °F (25°C)

| $I_{in}$ Amp | $E_{out}$ Volt | $I_{out}$ Amp | Freq CPS | Ripple P-P MV | $P_{in}$ Watt | $P_{out}$ Watt | EFF % | $V_{CE}$ (sat) M Volt |
|---|---|---|---|---|---|---|---|---|
| 15.0 | 28 | 0.535 | 585 | 145 | 24.0 | 15 | 62.5 | 36 |
| 19.0 | | 0.715 | 576 | 205 | 30.4 | 20 | 65.8 | |
| 22.3 | | 0.890 | 576 | 210 | 35.6 | 25 | 70.2 | |
| 26.2 | | 1.07 | 574 | 215 | 41.9 | 30 | 71.6 | 42 |
| 30.1 | | 1.25 | 569 | 220 | 48.1 | 35 | 72.8 | |
| 34.0 | | 1.43 | 566 | 230 | 54.4 | 40 | 73.5 | |
| 38.0 | | 1.61 | 566 | 230 | 60.8 | 45 | 74.1 | 45 |
| 41.8 | | 1.79 | 559 | 230 | 66.8 | 50 | 75.0 | |
| 45.5 | | 1.96 | 557 | 230 | 72.9 | 55 | 75.6 | |

$E_{in}$ 1.2 VDC OVERLOAD Temperature RM °F

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 60.3 | 27.9 | 2.0 | 406 | 64 | 72.4 | 55.8 | 77.0 | |
| 76.0 | 27.5 | 2.5 | 399 | 240 | 154.0 | 68.8 | 44.6 | |
| 70.2 | 20.8 | 3.0 | 401 | 340 | 84.0 | 62.4 | 74.0 | |
| 15.9 | 2.2 | 3.5 | 462 | 290 | 19.1 | 7.7 | 40.3 | |
| 8.8 | 0.2 | 3.56 | 727 | 140 | 10.6 | 0.7 | 6.7 | |
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LIV Converter
EXG 2424
50 Watt
$E_{in(min)} = 1.2$

$E_{in}$ 1.6 VDC OVERLOAD Temperature RM °F (25°C)

| $I_{in}$ Amp | $E_{out}$ Volt | $I_{out}$ Amp | Freq CPS | Ripple P-P MV | $P_{in}$ Watt | $P_{out}$ Watt | EFF % | $V_{CE}$ (sat) M Volt |
|---|---|---|---|---|---|---|---|---|
| 46.4 | 28 | 2.0 | 557 | 250 | 72.8 | 56.0 | 77 | |
| 58.0 | 28 | 2.5 | 546 | 340 | 92.8 | 70.0 | 75.5 | |
| 68.0 | 27.5 | 3.0 | 537 | 480 | 109.0 | 82.5 | 75.5 | |
| 45.3 | 14.3 | 3.5 | 561 | 400 | 72.5 | 50.0 | 69.0 | |
| 9.0 | 0.2 | 3.9 | 520 | 200 | 14.4 | 0.78 | 5.4 | |
| | | | | | | | | |
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$E_{in}$ 0.8 VDC $E_{in(min)} = 0.68$ OVERLOAD Temperature RM °F

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 89.2 | 25.2 | 2.0 | 802 | 100 | 71.4 | 50.4 | 70.5 | |
| 110 | 23.1 | 2.5 | 757 | 275 | 88.0 | 57.8 | 65.6 | |
| 126.0 | 20.8 | 3.0 | 739 | 550 | 108.0 | 62.4 | 57.7 | |
| 29.5 | 3.5 | 3.5 | 447 | 330 | 23.6 | 12.3 | 52.1 | |
| 12 | 0.2 | 3.55 | 458 | 130 | 9.6 | 0.71 | 7.4 | |
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OEXM 10810
DATE 3-24-64

LIV Converter
EXG 2424
50 Watt

$E_{in(min)} = 1.2$

$E_{in}$ 1.2 VDC   Temperature 158 °F (70°C)

| $I_{in}$ Amp | $E_{out}$ Volt | $I_{out}$ Amp | Freq CPS | Ripple P-P MV | $P_{in}$ Watt | $P_{out}$ Watt | EFF % | $V_{CE}$ (sat) M Volt |
|---|---|---|---|---|---|---|---|---|
| 18.6 | 28 | 0.535 | 436 | 60 | 22.3 | 15 | 67.2 | 42 |
| 23.4 | | 0.715 | 434 | 70 | 28.1 | 20 | 71.2 | |
| 28.2 | | 0.890 | 436 | 80 | 33.9 | 25 | 73.8 | |
| 33.4 | | 1.07 | 428 | 75 | 40.1 | 30 | 74.8 | 55 |
| 39.0 | | 1.250 | 428 | 80 | 46.8 | 35 | 75.0 | |
| 44.0 | | 1.430 | 428 | 80 | 52.8 | 40 | 75.8 | |
| 49.1 | | 1.610 | 423 | 80 | 59.0 | 45 | 76.2 | 70 |
| 54.7 | | 1.790 | 417 | 70 | 65.6 | 50 | 76.3 | |
| 60.0 | | 1.960 | 411 | 70 | 72.0 | 55 | 76.4 | |

$E_{in}$ 1.3 VDC   Temperature 158 °F

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 17.4 | 28 | 0.535 | 482 | 120 | 22.6 | 15 | 65.4 | 41 |
| 22.1 | | 0.715 | 475 | 105 | 28.8 | 20 | 69.5 | |
| 26.9 | | 0.890 | 469 | 110 | 35.0 | 25 | 71.4 | |
| 31.6 | | 1.07 | 467 | 115 | 41.1 | 30 | 73.0 | 53 |
| 36.3 | | 1.250 | 463 | 115 | 47.4 | 35 | 73.9 | |
| 41.2 | | 1.430 | 458 | 115 | 53.6 | 40 | 74.6 | |
| 45.9 | | 1.610 | 456 | 115 | 59.8 | 45 | 75.3 | 65 |
| 50.4 | | 1.790 | 456 | 120 | 65.5 | 50 | 76.4 | |
| 55.8 | | 1.960 | 449 | 115 | 72.5 | 55 | 75.9 | |

OEXM 10610
DATE 3-27-64

# LIV Converter
## EXG 2424
## 50 Watt

$E_{in(min)} = 1.2$

$E_{in}$ 1.4 VDC    Temperature 158 °F (70°C)

| $I_{in}$ Amp | $E_{out}$ Volt | $I_{out}$ Amp | Freq CPS | Ripple P-P MV | $P_{in}$ Watt | $P_{out}$ Watt | EFF % | $V_{CE}$ (sat) M Volt |
|---|---|---|---|---|---|---|---|---|
| 16.8 | 28 | 0.535 | 512 | 120 | 23.5 | 15 | 63.9 | 41 |
| 21.0 | | 0.715 | 513 | 125 | 29.4 | 20 | 68.0 | |
| 25.2 | | 0.890 | 507 | 130 | 35.3 | 25 | 70.9 | |
| 29.7 | | 1.07 | 504 | 140 | 41.6 | 30 | 72.2 | 52 |
| 34.1 | | 1.25 | 499 | 140 | 47.7 | 35 | 73.5 | |
| 38.8 | | 1.43 | 497 | 145 | 54.3 | 40 | 73.8 | |
| 43.2 | | 1.61 | 493 | 135 | 60.5 | 45 | 74.4 | 64 |
| 47.3 | | 1.79 | 480 | 140 | 66.2 | 50 | 75.6 | |
| 52.1 | | 1.96 | 485 | 145 | 73.0 | 55 | 75.4 | |

$E_{in}$ 1.5 VDC    Temperature 158 °F

| $I_{in}$ Amp | $E_{out}$ Volt | $I_{out}$ Amp | Freq CPS | Ripple P-P MV | $P_{in}$ Watt | $P_{out}$ Watt | EFF % | $V_{CE}$ (sat) M Volt |
|---|---|---|---|---|---|---|---|---|
| 16.0 | 28 | 0.535 | 579 | 150 | 24.0 | 15 | 62.5 | 41 |
| 20.0 | | 0.715 | 540 | 155 | 30.0 | 20 | 66.6 | |
| 24.0 | | 0.89 | 543 | 165 | 36.0 | 25 | 69.4 | |
| 28.0 | | 1.07 | 538 | 170 | 42.0 | 30 | 71.5 | 51 |
| 32.3 | | 1.25 | 535 | 170 | 48.5 | 35 | 72.2 | |
| 36.4 | | 1.43 | 534 | 175 | 54.6 | 40 | 73.2 | |
| 40.8 | | 1.61 | 529 | 180 | 61.1 | 45 | 73.6 | 63 |
| 44.6 | | 1.79 | 527 | 185 | 66.8 | 50 | 74.8 | |
| 48.5 | | 1.96 | 520 | 180 | 72.8 | 55 | 75.5 | |

OEXM 10610
DATE 3-27-67

LIV Converter
EXG 2424
50 Watt
$E_{in(min)} = 1.2$

$E_{in}$ 1.6 VDC Temperature 158 °F (70°C)

| $I_{in}$ Amp | $E_{out}$ Volt | $I_{out}$ Amp | Freq CPS | Ripple P-P MV | $P_{in}$ Watt | $P_{out}$ Watt | EFF % | $V_{CE}$ (sat) M Volt |
|---|---|---|---|---|---|---|---|---|
| 15.1 | 28 | 0.535 | 597 | 165 | 24.2 | 15 | 62.1 | 41 |
| 19.0 | | 0.715 | 581 | 170 | 30.4 | 20 | 65.8 | |
| 22.9 | | 0.89 | 580 | 175 | 36.6 | 25 | 68.3 | |
| 26.5 | | 1.07 | 578 | 185 | 42.4 | 30 | 70.8 | 51 |
| 30.8 | | 1.25 | 573 | 190 | 49.2 | 35 | 71.2 | |
| 34.5 | | 1.43 | 570 | 190 | 55.2 | 40 | 72.6 | |
| 38.6 | | 1.61 | 564 | 195 | 61.8 | 45 | 73.0 | 62 |
| 42.2 | | 1.79 | 563 | 200 | 67.5 | 50 | 74.2 | |
| 46.2 | | 1.96 | 559 | 210 | 73.8 | 55 | 74.5 | |

$E_{in}$ 1.2 VDC OVERLOAD. Temperature 158 °F

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 61.0 | 27.9 | 2.0 | 410 | 70 | 73.3 | 55.8 | 76.1 | |
| 76.5 | 27.0 | 2.5 | 391 | 230 | 91.7 | 67.5 | 73.6 | |
| 71.5 | 20.4 | 3.0 | 401 | 250 | 85.8 | 61.1 | 71.6 | |
| 26.8 | 5.0 | 3.5 | 438 | 270 | 32.2 | 18.5 | 57.5 | |
| 9.8 | 0.2 | 3.6 | 769 | 140 | 11.8 | 0.72 | 6.1 | |
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OEXM 10610
DATE 3-27-64

LIV Converter
EXG 2424
50 Watt
E in (min) = 1.2

$E_{in}$ 1.6 VDC OVERLOAD Temperature 158 °F (70°C)

| $I_{in}$ Amp | $E_{out}$ Volt | $I_{out}$ Amp | Freq CPS | Ripple P-P MV | $P_{in}$ Watt | $P_{out}$ Watt | EFF % | $V_{CE}$ (sat) M Volt |
|---|---|---|---|---|---|---|---|---|
| 47.2 | 28 | 2.0 | 559 | 120 | 75.5 | 56 | 74.2 | |
| 59.0 | 28 | 2.5 | 543 | 300 | 94.3 | 70 | 74.2 | |
| 70.0 | 27.7 | 3.0 | 531 | 400 | 112.0 | 83 | 74.0 | |
| 45.3 | 14.2 | 3.5 | 562 | 320 | 72.5 | 49.7 | 68.6 | |
| 10.0 | 0.2 | 3.8 | 533 | 170 | 16.0 | 0.76 | 4.8 | |
| | | | | | | | | |
| | | | | | | | | |
| | | | | | | | | |
| | | | | | | | | |

$E_{in}$ 0.8 VDC E in (min) = 0.8 OVERLOAD Temperature 158 °F

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 91.6 | 24.4 | 2.0 | 770 | 60 | 73.3 | 48.8 | 66.5 | |
| 114 | 21.7 | 2.5 | 722 | 60 | 91.2 | 54.3 | 59.5 | |
| 130 | 18.0 | 3.0 | 672 | 360 | 104.0 | 54.0 | 51.9 | |
| 12.3 | 0.2 | 3.6 | 759 | 130 | 9.8 | 0.72 | 7.3 | |
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OEXM 10610
DATE 3-27-64

LIV Converter
EXG 2424
50 Watt

$E_{in\,(min)} = 1.2$

$E_{in}$ 1.2 VDC Temperature 14 °F (−10°C)

| $I_{in}$ Amp | $E_{out}$ Volt | $I_{out}$ Amp | Freq CPS | Ripple P-P MV | $P_{in}$ Watt | $P_{out}$ Watt | EFF % | $V_{CE}$ (sat) M Volt |
|---|---|---|---|---|---|---|---|---|
| 18.5 | 27.7 | 0.535 | 436 | 125 | 22.2 | 14.8 | 66.8 | 35.0 |
| 23.0 | 27.7 | 0.715 | 433 | 125 | 27.6 | 19.8 | 71.8 | |
| 28.0 | 27.7 | 0.89 | 428 | 125 | 33.6 | 24.7 | 73.4 | |
| 33.0 | 27.6 | 1.07 | 425 | 125 | 39.6 | 29.6 | 74.8 | 41 |
| 38.0 | 27.6 | 1.25 | 422 | 125 | 45.5 | 34.5 | 76.0 | |
| 43.0 | 27.6 | 1.43 | 418 | 125 | 51.6 | 39.5 | 76.5 | |
| 48.0 | 27.6 | 1.61 | 416 | 130 | 57.6 | 44.4 | 77.2 | 48 |
| 52.2 | 27.6 | 1.79 | 418 | 150 | 62.7 | 49.4 | 78.8 | |
| 57.8 | 27.6 | 1.96 | 410 | 150 | 68.4 | 54.1 | 79.0 | |

$E_{in}$ 1.3 VDC Temperature 14 °F

| $I_{in}$ Amp | $E_{out}$ Volt | $I_{out}$ Amp | Freq CPS | Ripple P-P MV | $P_{in}$ Watt | $P_{out}$ Watt | EFF % | $V_{CE}$ (sat) M Volt |
|---|---|---|---|---|---|---|---|---|
| 17.6 | 27.8 | 0.535 | 474 | 185 | 22.9 | 14.9 | 65.0 | 34 |
| 22.0 | 27.8 | 0.715 | 468 | 195 | 28.6 | 19.9 | 69.5 | |
| 26.5 | 27.8 | 0.89 | 462 | 185 | 34.4 | 24.8 | 72.0 | |
| 30.9 | 27.8 | 1.07 | 462 | 190 | 40.2 | 29.8 | 74.1 | 40 |
| 35.2 | 27.8 | 1.25 | 460 | 190 | 45.7 | 34.7 | 74.5 | |
| 40.1 | 27.8 | 1.43 | 458 | 195 | 52.1 | 39.7 | 76.3 | |
| 44.8 | 27.8 | 1.61 | 454 | 210 | 58.2 | 44.8 | 77.0 | 47 |
| 49.0 | 27.5 | 1.79 | 457 | 220 | 63.7 | 49.8 | 78.0 | |
| 54.0 | 27.8 | 1.96 | 446 | 210 | 70.2 | 54.5 | 77.6 | |

OEXM 10-10
DATE 3-26-64

LIV Converter
EXG 2424
50 Watt

$E_{in(min)} = 1.2$

$E_{in}$ 1.4 VDC    Temperature 14 °F (-10 °C)

| $I_{in}$ Amp | $E_{out}$ Volt | $I_{out}$ Amp | Freq CPS | Ripple P-P MV | $P_{in}$ Watt | $P_{out}$ Watt | EFF % | $V_{CE}$ (sat) M Volt |
|---|---|---|---|---|---|---|---|---|
| 16.8 | 27.8 | 0.535 | 510 | 220 | 23.5 | 14.9 | 63.4 | 34 |
| 21.0 | 27.8 | 0.715 | 504 | 230 | 29.4 | 19.9 | 67.8 | |
| 24.8 | 27.8 | 0.89 | 497 | 230 | 34.7 | 24.7 | 71.2 | |
| 29.1 | 27.8 | 1.07 | 494 | 230 | 40.7 | 29.8 | 73.3 | 39 |
| 33.2 | 27.8 | 1.25 | 493 | 230 | 46.5 | 34.8 | 74.8 | |
| 38.0 | 27.8 | 1.43 | 492 | 250 | 53.2 | 39.8 | 75.0 | |
| 42.0 | 27.8 | 1.61 | 489 | 250 | 58.8 | 44.8 | 76.1 | 46 |
| 46.2 | 27.8 | 1.79 | 487 | 260 | 64.5 | 49.8 | 77.2 | |
| 50.5 | 27.8 | 1.96 | 481 | 250 | 70.7 | 54.5 | 77.2 | |

$E_{in}$ 1.5 VDC    Temperature 14 °F

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 16.0 | 28 | 0.535 | 554 | 265 | 24.0 | 15 | 62.5 | 34 |
| 20.0 | | 0.715 | 539 | 270 | 30.0 | 20 | 66.6 | |
| 23.7 | | 0.89 | 528 | 270 | 35.6 | 25 | 70.3 | |
| 27.8 | | 1.07 | 530 | 270 | 41.7 | 30 | 72.0 | 39 |
| 31.6 | | 1.25 | 532 | 280 | 47.4 | 35 | 73.8 | |
| 35.8 | | 1.43 | 526 | 230 | 53.7 | 40 | 74.6 | |
| 39.9 | | 1.61 | 523 | 290 | 59.9 | 45 | 75.4 | 45 |
| 43.8 | | 1.79 | 521 | 300 | 65.7 | 50 | 76.1 | |
| 47.7 | | 1.96 | 518 | 310 | 71.4 | 55 | 77.1 | |

OEXM 10610
DATE 3-26-61

LIV Converter
EXG 2424
50 Watt

$E_{in(min)} = 1.2$

$E_{in}$ 1.6 VDC Temperature 14 °F (−10°C)

| $I_{in}$ Amp | $E_{out}$ Volt | $I_{out}$ Amp | Freq CPS | Ripple P-P MV | $P_{in}$ Watt | $P_{out}$ Watt | EFF % | $V_{CE}$ (sat) M Volt |
|---|---|---|---|---|---|---|---|---|
| 15.2 | 28 | 0.535 | 587 | 290 | 24.3 | 15 | 61.9 | 34 |
| 19.0 | | 0.715 | 569 | 295 | 30.4 | 20 | 65.8 | |
| 22.8 | | 0.89 | 570 | 295 | 36.5 | 25 | 68.5 | |
| 26.3 | | 1.07 | 568 | 305 | 42.1 | 30 | 71.3 | 38 |
| 30.1 | | 1.25 | 559 | 310 | 48.2 | 35 | 72.7 | |
| 34.0 | | 1.43 | 560 | 320 | 54.4 | 40 | 73.6 | |
| 37.9 | | 1.61 | 561 | 335 | 60.6 | 45 | 74.3 | 44 |
| 41.5 | | 1.79 | 554 | 340 | 66.4 | 50 | 75.2 | |
| 45.0 | | 1.96 | 577 | 350 | 72.0 | 55 | 76.4 | |

$E_{in}$ 1.2 VDC OVERLOAD Temperature 14 °F

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 59.6 | 27.7 | 2.0 | 409 | 110 | 71.5 | 55.4 | 77.5 | |
| 71.5 | 27.6 | 2.5 | 400 | 220 | 90.5 | 69.0 | 76.3 | |
| 69.5 | 21.0 | 3.0 | 409 | 400 | 83.6 | 63.0 | 75.3 | |
| 8.8 | 0.2 | 3.5 | 675 | 140 | 10.5 | 0.7 | 6.6 | |

OEXM 10510
DATE 3-26-64

LIV Converter
EXG 2424
50 Watt
$E_{in\,(min)} = 1.2$

$E_{in}$ 1.6 VDC OVERLOAD Temperature 14 °F (−10°C)

| $I_{in}$ Amp | $E_{out}$ Volt | $I_{out}$ Amp | Freq CPS | Ripple P-P MV | $P_{in}$ Watt | $P_{out}$ Watt | EFF % | $V_{CE\,(sat)}$ M Volt |
|---|---|---|---|---|---|---|---|---|
| 46.0 | 28.0 | 2.0 | 553 | 360 | 73.6 | 56 | 76.1 | |
| 57.0 | 28.0 | 2.5 | 547 | 480 | 91.1 | 70 | 76.8 | |
| 66.8 | 27.3 | 3.0 | 537 | 640 | 107 | 81.8 | 76.5 | |
| 38.2 | 11.8 | 3.5 | 554 | 500 | 61.0 | 41.4 | 68.0 | |
| 9.0 | 0.2 | 3.7 | 521 | 300 | 14.4 | 0.74 | 5.1 | |
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$E_{in}$ 0.8 VDC OVERLOAD $E_{in\,(min)} = 0.8$ Temperature 14 °F

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 88.5 | 26.0 | 2.0 | 817 | 120 | 70.8 | 52.0 | 73.4 | |
| 109.5 | 24.1 | 2.5 | 778 | 350 | 87.6 | 60.3 | 68.8 | |
| * | | 3.0 | | | | | | |
| 11.0 | 0.2 | 3.4 | 491 | 140 | 8.8 | 0.7 | 7.9 | |
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* Unstable

OEXM 10610
DATE 3-26-64

LIV Converter
EXG 2424
50 Watt

$E_{in(min)} = 1.2$

$E_{in}$ 1.2 VDC  Temperature -65 °F (-54°C)

| $I_{in}$ Amp | $E_{out}$ Volt | $I_{out}$ Amp | Freq CPS | Ripple P-P MV | $P_{in}$ Watt | $P_{out}$ Watt | EFF % | $V_{CE}$ (sat) M Volt |
|---|---|---|---|---|---|---|---|---|
| 18.1 | 27.4 | 0.535 | 462 | 290 | 21.7 | 14.65 | 67.5 | |
| 23.0 | 27.4 | 0.715 | 430 | 300 | 27.6 | 19.60 | 72.0 | |
| 27.5 | 27.4 | 0.89 | 425 | 300 | 33.0 | 24.4 | 74.0 | |
| 32.5 | 27.4 | 1.07 | 421 | 290 | 39.0 | 29.3 | 75.2 | |
| 37.2 | 27.4 | 1.25 | 420 | 290 | 44.6 | 34.3 | 76.8 | |
| 42.0 | 27.4 | 1.43 | 420 | 290 | 50.4 | 39.2 | 77.8 | |
| 47.0 | 27.4 | 1.61 | 415 | 290 | 56.4 | 44.2 | 78.4 | |
| 52.0 | 27.4 | 1.79 | 416 | 290 | 62.4 | 49.0 | 78.5 | |
| 57.0 | 27.4 | 1.96 | 411 | 370 | 68.4 | 53.8 | 78.6 | |

$E_{in}$ 1.3 VDC  Temperature -65 °F

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 17.5 | 27.6 | 0.535 | 499 | 460 | 22.7 | 14.8 | 65.0 | |
| 21.8 | 27.6 | 0.715 | 462 | 460 | 28.4 | 19.7 | 69.5 | |
| 26.0 | 27.6 | 0.89 | 460 | 460 | 33.8 | 24.6 | 72.7 | |
| 30.2 | 27.5 | 1.07 | 459 | 470 | 39.6 | 29.5 | 74.5 | |
| 35.0 | 27.5 | 1.25 | 458 | 480 | 45.5 | 34.4 | 75.7 | |
| 39.6 | 27.5 | 1.43 | 456 | 490 | 51.5 | 39.3 | 76.8 | |
| 44.0 | 27.5 | 1.61 | 455 | 490 | 57.2 | 44.3 | 77.5 | |
| 48.6 | 27.5 | 1.79 | 448 | 490 | 63.2 | 49.3 | 78.0 | |
| 53.0 | 27.5 | 1.96 | 446 | 490 | 69.0 | 54 | 78.3 | |

OEXM 10610
DATE 3-26-64

LIV Converter
EXG 2424
50 Watt
$E_{in(min)}$ = 1.2

$E_{in}$ 1.4 VDC    Temperature -65 °F (-54°C)

| $I_{in}$ Amp | $E_{out}$ Volt | $I_{out}$ Amp | Freq CPS | Ripple P-P MV | $P_{in}$ Watt | $P_{out}$ Watt | EFF % | $V_{CE}$ (sat) M Volt |
|---|---|---|---|---|---|---|---|---|
| 16.8 | 27.7 | 0.535 | 534 | 580 | 23.5 | 14.8 | 63.2 | |
| 20.8 | 27.7 | 0.715 | 499 | 600 | 29.1 | 19.8 | 68.0 | |
| 24.8 | 27.7 | 0.89 | 489 | 590 | 34.7 | 24.7 | 71.2 | |
| 28.8 | 27.7 | 1.07 | 493 | 600 | 40.3 | 29.6 | 73.5 | |
| 33.0 | 27.7 | 1.25 | 488 | 600 | 46.2 | 34.6 | 75.0 | |
| 37.2 | 27.7 | 1.43 | 489 | 610 | 52.0 | 39.6 | 76.2 | |
| 41.6 | 27.7 | 1.61 | 485 | 620 | 58.2 | 44.6 | 76.6 | |
| 45.7 | 27.7 | 1.79 | 483 | 640 | 64.0 | 49.6 | 77.6 | |
| 50.1 | 27.7 | 1.96 | 477 | 650 | 70.1 | 54.3 | 77.4 | |

$E_{in}$ 1.5 VDC    Temperature -65 °F

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 16.0 | 27.8 | 0.535 | 574 | 680 | 24.0 | 14.9 | 62.0 | |
| 20.0 | 27.8 | 0.715 | 530 | 690 | 30.0 | 19.9 | 66.6 | |
| 23.5 | 27.8 | 0.89 | 523 | 690 | 35.3 | 24.7 | 70.0 | |
| 27.4 | 27.8 | 1.07 | 525 | 700 | 41.2 | 29.8 | 72.4 | |
| 31.2 | 27.8 | 1.25 | 519 | 720 | 46.8 | 34.8 | 74.4 | |
| 35.2 | 27.8 | 1.43 | 521 | 740 | 52.8 | 39.8 | 75.4 | |
| 39.0 | 27.8 | 1.61 | 522 | 760 | 58.5 | 44.8 | 76.6 | |
| 43.1 | 27.8 | 1.79 | 515 | 760 | 64.6 | 49.8 | 77.0 | |
| 46.9 | 27.8 | 1.96 | 515 | 800 | 70.2 | 54.5 | 77.8 | |

OEXM 10610
DATE 3-26-64

LIV Converter
EXG 2424
50 Watt

E in(min) = 1.2

$E_{in}$ 1.6 VDC Temperature -65 °F (-54°C)

| $I_{in}$ Amp | $E_{out}$ Volt | $I_{out}$ Amp | Freq CPS | Ripple P-P MV | $P_{in}$ Watt | $P_{out}$ Watt | EFF % | $V_{CE}$ (sat) M Volt |
|---|---|---|---|---|---|---|---|---|
| 15.5 | 28 | 0.535 | 615 | 780 | 24.8 | 15 | 60.5 | |
| 19.2 | | 0.715 | 570 | 790 | 30.7 | 20 | 65.2 | |
| 22.7 | | 0.89 | 561 | 800 | 36.4 | 25 | 68.8 | |
| 26.1 | | 1.07 | 558 | 800 | 41.7 | 30 | 72.0 | |
| 29.9 | | 1.25 | 551 | 800 | 48.0 | 35 | 72.8 | |
| 33.8 | | 1.43 | 554 | 820 | 54.1 | 40 | 74.0 | |
| 37.2 | | 1.61 | 554 | 840 | 59.5 | 45 | 75.6 | |
| 41.0 | | 1.79 | 550 | 860 | 65.6 | 50 | 76.2 | |
| 44.9 | | 1.96 | 543 | 880 | 71.9 | 55 | 76.6 | |

$E_{in}$ 1.2 VDC OVERLOAD Temperature -65 °F

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 58.0 | 27.4 | 2.0 | 412 | 330 | 69.6 | 54.8 | 78.6 | |
| 73.0 | 27.0 | 2.5 | 567 | 680 | 87.6 | 67.5 | 77.2 | |
| 43.1 | 12.3 | 3.0 | 425 | 650 | 51.6 | 36.9 | 71.5 | |
| 8.1 | 0.2 | 3.2 | 417 | 120 | 9.7 | 0.64 | 6.5 | |
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OEXM 10610
DATE 3-26-64

LIV Converter
EXG 2424
50 Watt

$E_{in}$ (min) = 1.2

$E_{in}$ 1.6 VDC OVERLOAD Temperature -65 °F -54°C

| $I_{in}$ Amp | $E_{out}$ Volt | $I_{out}$ Amp | Freq CPS | Ripple P-P MV | $P_{in}$ Watt | $P_{out}$ Watt | EFF % | $V_{CE}$ (sat) M Volt |
|---|---|---|---|---|---|---|---|---|
| 45.2 | 28.0 | 2.0 | 550 | 900 | 72.3 | 56.0 | 77.6 | |
| 56.2 | 27.8 | 2.5 | 540 | 1390 | 90.0 | 69.5 | 77.3 | |
| 56.1 | 22.8 | 3.0 | 540 | 800 | 89.9 | 68.4 | 76.2 | |
| 7.6 | 0.2 | 3.4 | 515 | 180 | 12.2 | 0.7 | 5.9 | |
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$E_{in}$ 0.8 VDC OVERLOAD Temperature -65 °F

$E_{in}$ (min) = 0.8

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 90.0 | 26.6 | 2.0 | 410 | 850 | 72.0 | 53.2 | 73.8 | |
| * | | 2.5 | | | | | | |
| * | | 3.0 | | | | | | |
| 10.5 | 0.2 | 3.3 | 528 | 115 | 8.4 | 0.66 | 7.9 | |
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* Unstable

OEXM 10-10
DATE 3-20-71

**LIV Converter**
**EXG 2424**
**50 Watt**

$E_{i\,(min)} = 0.8$

$E_{in}$ 0.8 VDC    Temperature 158 °F (70 °C)

| $I_{in}$ Amp | $E_{out}$ Volt | $I_{out}$ Amp | Freq CPS | Ripple P-P MV | $P_{in}$ Watt | $P_{out}$ Watt | EFF % | $V_{CE}$ (sat) M Volt |
|---|---|---|---|---|---|---|---|---|
| 26.6 | 28.0 | 0.535 | 447 | 75 | 21.3 | 15.0 | 70.5 | 52 |
| 34.9 | 28.0 | 0.715 | 439 | 70 | 27.9 | 20.0 | 71.8 | |
| 43.0 | 27.8 | 0.890 | 426 | 60 | 34.4 | 24.8 | 73.0 | |
| 50.7 | 27.8 | 1.070 | 430 | 70 | 40.5 | 29.8 | 73.5 | 70 |
| 58.3 | 27.4 | 1.250 | 428 | 70 | 46.6 | 34.3 | 73.5 | |
| 66.2 | 26.9 | 1.430 | 417 | 70 | 53.0 | 38.4 | 72.6 | |
| 73.6 | 26.1 | 1.610 | 817 | 70 | 58.9 | 42.1 | 71.5 | 85 |
| 80.9 | 25.5 | 1.790 | 798 | 65 | 64.1 | 45.6 | 70.5 | |
| 87.8 | 24.4 | 1.960 | 784 | 70 | 70.2 | 47.9 | 68.1 | |

$E_{in}$ 0.9 VDC    Temperature 158 °F

| $I_{in}$ Amp | $E_{out}$ Volt | $I_{out}$ Amp | Freq CPS | Ripple P-P MV | $P_{in}$ Watt | $P_{out}$ Watt | EFF % | $V_{CE}$ (sat) M Volt |
|---|---|---|---|---|---|---|---|---|
| 24.5 | 28.0 | 0.535 | 455 | 115 | 22.1 | 15.0 | 68.0 | 49 |
| 31.5 | 28.0 | 0.715 | 497 | 125 | 28.4 | 20.0 | 70.4 | |
| 38.2 | 28.0 | 0.890 | 494 | 125 | 34.4 | 25.0 | 72.8 | |
| 45.5 | 28.0 | 1.070 | 487 | 125 | 41.0 | 30.0 | 73.2 | 67 |
| 52.5 | 28.0 | 1.25 | 480 | 120 | 47.5 | 35.0 | 73.5 | |
| 61.2 | 28.0 | 1.43 | 469 | 120 | 55.0 | 40.0 | 72.8 | |
| 70.0 | 28.0 | 1.61 | 471 | 120 | 63.0 | 45.0 | 71.2 | 85 |
| 83.0 | 27.8 | 1.79 | 425 | 120 | 74.6 | 49.8 | 67.2 | |
| 87.8 | 27.6 | 1.96 | 430 | 60 | 79.0 | 54.1 | 68.4 | |

OEXM 10610
DATE 3-28-61

LIV Converter
EXG 2424
50 Watt

$E_{in(min)} = 0.8$

$E_{in}$ 1.0 VDC  Temperature 158 °F (70°C)

| $I_{in}$ Amp | $E_{out}$ Volt | $I_{out}$ Amp | Freq CPS | Ripple P-P MV | $P_{in}$ Watt | $P_{out}$ Watt | EFF % | $V_{CE}$ (sat) M Volt |
|---|---|---|---|---|---|---|---|---|
| 23.0 | 28.2 | 0.535 | 554 | 150 | 23.0 | 15.2 | 66.0 | 47 |
| 29.2 | 28.2 | 0.715 | 548 | 150 | 29.2 | 20.1 | 69.0 | |
| 35.2 | 28 | 0.890 | 547 | 160 | 35.2 | 25 | 71.1 | |
| 42.0 | | 1.070 | 546 | 160 | 42.0 | 30 | 71.4 | 63 |
| 49.0 | | 1.25 | 524 | 160 | 49.0 | 35 | 71.4 | |
| 55.5 | | 1.43 | 524 | 160 | 55.5 | 40 | 72.0 | |
| 62.0 | | 1.61 | 522 | 160 | 62.0 | 45 | 72.6 | 84 |
| 68.5 | | 1.79 | 516 | 170 | 68.5 | 50 | 73.0 | |
| * | | | | | | | | |

$E_{in}$ 1.1 VDC  Temperature 158 °F

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 21.6 | 28.2 | 0.535 | 609 | 170 | 24.0 | 15.2 | 63.2 | 46 |
| 27.5 | | 0.715 | 602 | 170 | 30.3 | 20.1 | 66.4 | |
| 33.0 | | 0.890 | 602 | 190 | 36.3 | 25.1 | 69.1 | |
| 39.2 | | 1.070 | 590 | 190 | 43.1 | 30.1 | 70.0 | 60 |
| 44.8 | | 1.25 | 588 | 195 | 49.2 | 35.1 | 71.4 | |
| 51.2 | | 1.43 | 576 | 195 | 56.2 | 40.2 | 71.8 | |
| 56.8 | | 1.61 | 570 | 200 | 62.4 | 45.4 | 72.8 | 78 |
| 63.0 | | 1.79 | 555 | 210 | 69.3 | 50.5 | 73.0 | |
| 69.3 | | 1.96 | 564 | 215 | 75.1 | 55.3 | 73.8 | |

* Unstable

OEXM 10810
DATE 3-28-64

**LIV Converter**
**EXG 2424**
**50 Watt**

$E_{in(min)} = 0.8$

$E_{in}$ 1.2 VDC    Temperature 158 °F (70°C)

| $I_{in}$ Amp | $E_{out}$ Volt | $I_{out}$ Amp | Freq CPS | Ripple P-P MV | $P_{in}$ Watt | $P_{out}$ Watt | EFF % | $V_{CE}$ (sat) M Volt |
|---|---|---|---|---|---|---|---|---|
| 21.0 | 28.2 | 0.535 | 663 | 200 | 25.2 | 15.2 | 60.4 | 44 |
| 26.0 | 28.2 | 0.715 | 660 | 210 | 31.2 | 20.1 | 64.4 | |
| 31.0 | 28.2 | 0.890 | 658 | 210 | 37.2 | 25.1 | 67.4 | |
| 36.8 | 28.2 | 1.07 | 648 | 210 | 44.2 | 30.1 | 68.2 | 58 |
| 42.2 | 28.2 | 1.25 | 639 | 220 | 50.7 | 35.1 | 69.1 | |
| 47.5 | 28.2 | 1.43 | 636 | 230 | 57.0 | 40.2 | 70.6 | |
| 53.0 | 28.2 | 1.61 | 631 | 230 | 63.6 | 45.4 | 71.5 | 74 |
| 58.5 | 28.2 | 1.79 | 624 | 240 | 70.2 | 50.5 | 72.0 | |
| 63.0 | 28.2 | 1.96 | 624 | 250 | 75.6 | 55.3 | 73.1 | |

$E_{in}$ 1.3 VDC    Temperature 158 °F

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 20.0 | 28.4 | 0.535 | 715 | 210 | 26.0 | 15.3 | 58.8 | 43 |
| 25.0 | 28.4 | 0.715 | 716 | 210 | 32.5 | 20.3 | 62.4 | |
| 29.8 | 28.4 | 0.89 | 708 | 220 | 38.7 | 25.3 | 65.3 | |
| 34.5 | 28.4 | 1.07 | 705 | 230 | 44.9 | 30.4 | 67.8 | 56 |
| 39.8 | 28.4 | 1.25 | 695 | 240 | 51.7 | 35.5 | 68.6 | |
| 44.6 | 28.4 | 1.43 | 691 | 240 | 58.0 | 40.6 | 70.1 | |
| 50.0 | 28.4 | 1.61 | 684 | 240 | 65.0 | 45.7 | 70.4 | 70 |
| 54.8 | 28.4 | 1.79 | 680 | 250 | 71.3 | 50.8 | 71.2 | |
| 60.2 | 28.4 | 1.96 | 676 | 270 | 78.4 | 55.7 | 71.0 | |

OEXM 10 [illegible]
DATE 3-25-64

LIV Converter
EXG 2424
50 Watt

$E_{in(min)} = 0.8$

$E_{in}$ 1.4 VDC Temperature 158 °F (70 °C)

| $I_{in}$ Amp | $E_{out}$ Volt | $I_{out}$ Amp | Freq CPS | Ripple P-P MV | $P_{in}$ Watt | $P_{out}$ Watt | EFF % | $V_{CE}$ (sat) M Volt |
|---|---|---|---|---|---|---|---|---|
| 19.2 | 28.4 | 0.535 | 768 | 250 | 26.9 | 15.2 | 56.5 | 43 |
| 23.6 | 28.2 | 0.715 | 764 | 240 | 33.0 | 20.1 | 60.9 | |
| 28.2 | 28.2 | 0.890 | 562 | 240 | 39.5 | 25.1 | 63.5 | |
| 33.0 | 28.2 | 1.07 | 754 | 250 | 46.2 | 30.1 | 65.1 | 54 |
| 37.5 | 28.2 | 1.25 | 755 | 260 | 52.5 | 35.2 | 67.1 | |
| 42.5 | 28.4 | 1.43 | 750 | 260 | 59.5 | 40.6 | 68.2 | |
| 47.0 | 28.4 | 1.61 | 743 | 270 | 65.8 | 45.7 | 69.4 | 68 |
| 51.8 | 28.4 | 1.79 | 738 | 280 | 72.5 | 50.8 | 70.0 | |
| 57.5 | 28.4 | 1.96 | 725 | 290 | 80.5 | 55.7 | 69.1 | |

$E_{in}$ 1.5 VDC Temperature 158 °F

| $I_{in}$ Amp | $E_{out}$ Volt | $I_{out}$ Amp | Freq CPS | Ripple P-P MV | $P_{in}$ Watt | $P_{out}$ Watt | EFF % | $V_{CE}$ (sat) M Volt |
|---|---|---|---|---|---|---|---|---|
| 18.3 | 28.2 | 0.535 | 820 | 240 | 27.4 | 15.2 | 55.4 | 42 |
| 22.8 | 28 | 0.715 | 815 | 250 | 34.2 | 20.0 | 58.4 | |
| 27.0 | 28 | 0.89 | 809 | 260 | 40.5 | 25.0 | 61.7 | |
| 31.2 | 28 | 1.07 | 811 | 270 | 46.8 | 30.0 | 64.1 | 53 |
| 35.5 | 28 | 1.25 | 809 | 280 | 53.2 | 35.0 | 65.7 | |
| 40.0 | 28 | 1.43 | 806 | 280 | 60.0 | 40.0 | 66.6 | |
| 44.2 | 28 | 1.61 | 793 | 300 | 66.3 | 45.0 | 67.8 | 66 |
| 48.5 | 28 | 1.79 | 791 | 320 | 72.8 | 50.0 | 68.6 | |
| 53.1 | 28 | 1.96 | 734 | 325 | 79.7 | 55.0 | 69.0 | |

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**LIV Converter**
**EXG 2424**
**50 Watt**

$E_{in(min)} = 0.8$

$E_{in}$ 1.6 VDC Temperature 158 °F (70°C)

| $I_{in}$ Amp | $E_{out}$ Volt | $I_{out}$ Amp | Freq CPS | Ripple P-P MV | $P_{in}$ Watt | $P_{out}$ Watt | EFF % | $V_{CE}$ (sat) M Volt |
|---|---|---|---|---|---|---|---|---|
| 17.7 | 28.2 | 0.535 | 889 | 240 | 28.3 | 15.1 | 53.3 | 41 |
| 21.9 | 28.0 | 0.715 | 873 | 270 | 35.0 | 20.0 | 57.1 | |
| 26.0 | 28.0 | 0.89 | 873 | 270 | 41.6 | 25.0 | 60.0 | |
| 30.0 | 28.0 | 1.07 | 870 | 280 | 48.0 | 30.0 | 62.5 | 52 |
| 34.0 | 28.0 | 1.25 | 856 | 280 | 54.4 | 35.0 | 64.3 | |
| 38.4 | 28.0 | 1.43 | 854 | 290 | 61.4 | 40.0 | 65.1 | |
| 42.8 | 28.0 | 1.61 | 848 | 300 | 68.5 | 45.0 | 65.6 | 64 |
| 46.6 | 28.0 | 1.79 | 845 | 310 | 74.6 | 50.0 | 67.0 | |
| 50.5 | 28.0 | 1.96 | 842 | 330 | 80.8 | 55.0 | 68.0 | |

$E_{in}$ 0.8 VDC Temperature Rm °F (25°C)

| $I_{in}$ Amp | $E_{out}$ Volt | $I_{out}$ Amp | Freq CPS | Ripple P-P MV | $P_{in}$ Watt | $P_{out}$ Watt | EFF % | $V_{CE}$ (sat) M Volt |
|---|---|---|---|---|---|---|---|---|
| 26.8 | 28 | 0.535 | 442 | 80 | 21.4 | 15 | 70.0 | 44 |
| 34.5 | 28 | 0.715 | 437 | 80 | 27.6 | 20 | 72.4 | |
| 42.3 | 27.8 | 0.89 | 433 | 80 | 33.8 | 24.7 | 73.0 | |
| 49.5 | 27.5 | 1.07 | 429 | 80 | 39.6 | 29.4 | 74.2 | 57 |
| 57.4 | 27.1 | 1.25 | 424 | 88 | 45.9 | 33.9 | 73.8 | |
| 65.8 | 27.1 | 1.43 | 428 | 90 | 52.6 | 38.8 | 73.7 | |
| 72.2 | 26.4 | 1.61 | 416 | 95 | 57.8 | 42.5 | 73.5 | 70 |
| 80.0 | 26.2 | 1.79 | 415 | 100 | 64.0 | 46.9 | 73.2 | |
| 87.0 | 25.4 | 1.96 | 405 | 100 | 69.6 | 49.8 | 71.5 | |

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LIV Converter
EXG 2424
50 Watt

$E_{in\,(min)} = 0.8$

$E_{in}$ 0.9 VDC    Temperature RM. °F (25°C)

| $I_{in}$ Amp | $E_{out}$ Volt | $I_{out}$ Amp | Freq CPS | Ripple P-P MV | $P_{in}$ Watt | $P_{out}$ Watt | EFF % | $V_{CE}$ (sat) M Volt |
|---|---|---|---|---|---|---|---|---|
| 21.2 | 28.0 | 0.535 | 505 | 160 | 21.8 | 15.0 | 68.8 | 42 |
| 31.7 | 28.0 | 0.715 | 484 | 140 | 28.5 | 20.0 | 70.1 | |
| 38.1 | 28.0 | 0.89 | 485 | 150 | 34.3 | 25.0 | 72.8 | 53 |
| 45.2 | 28.0 | 1.07 | 482 | 150 | 40.7 | 30.0 | 73.7 | |
| 52.3 | 28.0 | 1.25 | 478 | 155 | 47.0 | 35.0 | 74.4 | |
| 60.2 | 28.0 | 1.43 | 478 | 165 | 54.2 | 40.0 | 73.8 | 69 |
| 67.0 | 28.0 | 1.61 | 471 | 150 | 60.3 | 45.0 | 74.0 | |
| 94.6 | 28.0 | 2.23 | 438 | 125 | 85.1 | 62.4 | 73.3 | |
| | | | | | | | | |

$E_{in}$ 1.0 VDC    Temperature RM °F

| $I_{in}$ Amp | $E_{out}$ Volt | $I_{out}$ Amp | Freq CPS | Ripple P-P MV | $P_{in}$ Watt | $P_{out}$ Watt | EFF % | $V_{CE}$ (sat) M Volt |
|---|---|---|---|---|---|---|---|---|
| 22.5 | 28.1 | .535 | [illegible] | 200 | 22.5 | 15.0 | 66.6 | 41 |
| 28.4 | 28.1 | 0.715 | 520 | 210 | 28.4 | 20.1 | 70.7 | |
| 35.0 | 28.1 | 0.89 | 540 | 210 | 35.0 | 25.0 | 71.4 | |
| 41.1 | 28.1 | 1.07 | 513 | 115 | 41.1 | 30.1 | 73.2 | 51 |
| 47.5 | 28.0 | 1.25 | 537 | 115 | 47.5 | 35 | 73.6 | |
| 54.0 | 28.0 | 1.43 | 535 | 120 | 54.0 | 40 | 74.0 | |
| 60.5 | 28.0 | 1.61 | 513 | 215 | 60.5 | 45 | 74.3 | 64 |
| 67.0 | 28.0 | 1.79 | 523 | 225 | 67.0 | 50 | 74.6 | |
| 74.0 | 28.0 | 1.96 | 527 | 210 | 74.0 | 55 | 67.5 | |

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LIV Converter
EXG 2424
50 Watt
$E_{in(min)} = 0.8$

$E_{in}$ 1.1 VDC Temperature RM °F (25°C)

| $I_{in}$ Amp | $E_{out}$ Volt | $I_{out}$ Amp | Freq CPS | Ripple P-P MV | $P_{in}$ Watt | $P_{out}$ Watt | EFF % | $V_{CE}$ (sat) M Volt |
|---|---|---|---|---|---|---|---|---|
| 21.2 | 28 | 0.535 | 603 | 240 | 23.3 | 15 | 64.3 | 39 |
| 26.8 | 28 | 0.715 | 600 | 240 | 29.5 | 20 | 67.7 | |
| 32.2 | 28 | 0.89 | 595 | 240 | 35.4 | 25 | 70.6 | |
| 38.0 | 28 | 1.07 | 598 | 260 | 41.8 | 30 | 71.7 | 49 |
| 44.0 | 28 | 1.25 | 585 | 260 | 48.4 | 35 | 72.3 | |
| 50.0 | 28 | 1.43 | 582 | 270 | 55.0 | 40 | 72.7 | |
| 55.3 | 28 | 1.61 | 585 | 270 | 60.5 | 45 | 74.3 | 62 |
| 61.2 | 28 | 1.79 | 571 | 270 | 67.3 | 50 | 74.2 | |
| 67.5 | 28 | 1.96 | 560 | 270 | 74.3 | 55 | 74.0 | |

$E_{in}$ 1.2 VDC Temperature RM °F

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 20.0 | 28.1 | 0.535 | 660 | 260 | 24.0 | 15 | 62.5 | 38 |
| 25.1 | 28.0 | 0.715 | 644 | 270 | 30.1 | 20 | 66.4 | |
| 30.3 | 28.0 | 0.89 | 646 | 275 | 36.4 | 25 | 68.6 | |
| 35.5 | 28.0 | 1.07 | 643 | 280 | 42.6 | 30 | 70.4 | 47 |
| 40.8 | 28.0 | 1.25 | 637 | 290 | 49.0 | 35 | 71.4 | |
| 46.1 | 28.0 | 1.43 | 641 | 300 | 55.3 | 40 | 72.3 | |
| 51.2 | 28 | 1.61 | 633 | 310 | 61.4 | 45 | 73.2 | 60 |
| 56.4 | 28 | 1.79 | 631 | 320 | 67.7 | 50 | 73.8 | |
| 62.0 | 28 | 1.96 | 611 | 320 | 74.4 | 55 | 73.9 | |

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LIV Converter
EXG 2424
50 Watt

$E_{in\,(min)} = 0.8$

$E_{in}$ 1.3 VDC    Temperature RM °F (25°C)

| $I_{in}$ Amp | $E_{out}$ Volt | $I_{out}$ Amp | Freq CPS | Ripple P-P MV | $P_{in}$ Watt | $P_{out}$ Watt | EFF % | $V_{CE}$ (sat) M Volt |
|---|---|---|---|---|---|---|---|---|
| 19.1 | 28 | 0.535 | 708 | 280 | 21.8 | 15 | 60.4 | 37 |
| 24.0 | | 0.715 | 703 | 290 | 31.2 | 20 | 64.1 | |
| 28.6 | | 0.89 | 701 | 300 | 37.2 | 25 | 67.2 | |
| 33.2 | | 1.07 | 695 | 295 | 43.2 | 30 | 69.4 | 45 |
| 38.2 | | 1.25 | 692 | 310 | 49.7 | 35 | 70.4 | |
| 43.2 | | 1.43 | 686 | 330 | 56.2 | 40 | 71.1 | |
| 48.0 | | 1.61 | 687 | 340 | 62.4 | 45 | 72.1 | 58 |
| 53.2 | | 1.79 | 677 | 350 | 69.2 | 50 | 72.2 | |
| 58.0 | | 1.96 | 679 | 370 | 75.4 | 55 | 72.9 | |

$E_{in}$ 1.4 VDC    Temperature RM °F

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 18.5 | 28.2 | 0.535 | 754 | 300 | 25.9 | 15.1 | 58.3 | 36 |
| 23.0 | 28.0 | 0.715 | 756 | 315 | 32.2 | 20 | 62.1 | |
| 27.1 | | 0.89 | 753 | 320 | 38.0 | 25 | 65.9 | |
| 31.8 | | 1.07 | 746 | 325 | 44.5 | 30 | 67.4 | 43 |
| 36.2 | | 1.25 | 746 | 340 | 50.7 | 35 | 69.0 | |
| 41.0 | | 1.43 | 745 | 360 | 57.4 | 40 | 69.6 | |
| 45.2 | | 1.61 | 738 | 370 | 63.3 | 45 | 71.0 | 56 |
| 50.2 | | 1.79 | 725 | 380 | 70.3 | 50 | 71.1 | |
| 54.5 | | 1.96 | 729 | 390 | 76.3 | 55 | 72.0 | |

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**LIV Converter**
**EXG 2424**
**50 Watt**

$E_{in}$ 1.5 VDC  $E_{in\,(min)}$ = 0.8  Temperature RM °F (25°C)

| $I_{in}$ Amp | $E_{out}$ Volt | $I_{out}$ Amp | Freq CPS | Ripple P-P MV | $P_{in}$ Watt | $P_{out}$ Watt | EFF % | $V_{CE}$ (sat) M Volt |
|---|---|---|---|---|---|---|---|---|
| 17.8 | 28.2 | 0.535 | 817 | 320 | 26.7 | 15.1 | 56.5 | 35 |
| 22.0 | 28.0 | 0.715 | 806 | 330 | 33.0 | 20 | 60.5 | |
| 26.0 | 28 | 0.89 | 802 | 340 | 39.0 | 25 | 64.1 | |
| 30.0 | 28 | 1.07 | 800 | 350 | 45.0 | 30 | 66.6 | 42 |
| 34.5 | 28 | 1.25 | 792 | 360 | 51.8 | 35 | 67.5 | |
| 38.8 | 28 | 1.43 | 790 | 390 | 58.2 | 40 | 68.7 | |
| 43.2 | 28 | 1.61 | 786 | 390 | 64.8 | 45 | 69.4 | 54 |
| 47.5 | 28 | 1.79 | 781 | 400 | 71.3 | 50 | 70.1 | |
| 51.3 | 28 | 1.96 | 784 | 420 | 77.0 | 55 | 71.4 | |

$E_{in}$ 1.6 VDC  Temperature RM °F

| $I_{in}$ Amp | $E_{out}$ Volt | $I_{out}$ Amp | Freq CPS | Ripple P-P MV | $P_{in}$ Watt | $P_{out}$ Watt | EFF % | $V_{CE}$ (sat) M Volt |
|---|---|---|---|---|---|---|---|---|
| 17.3 | 28 | 0.535 | 860 | 330 | 27.7 | 15 | 54.1 | 34 |
| 21.2 | 28 | 0.715 | 860 | 350 | 33.9 | 20 | 58.9 | |
| 25.0 | 28 | 0.89 | 860 | 360 | 40.0 | 25 | 62.5 | |
| 29.0 | 28 | 1.07 | 859 | 375 | 46.4 | 30 | 64.6 | 41 |
| 33.0 | 28 | 1.25 | 846 | 380 | 52.8 | 35 | 66.2 | |
| 37.0 | 28 | 1.43 | 847 | 390 | 59.2 | 40 | 67.5 | |
| 41.0 | 28 | 1.61 | 831 | 400 | 65.6 | 45 | 68.5 | 53 |
| 45.0 | 28 | 1.79 | 836 | 410 | 72.0 | 50 | 69.4 | |
| 49.2 | 28 | 1.96 | 832 | 420 | 78.7 | 55 | 69.8 | |

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LIV Converter
EXG 2424
50 Watt
$E_{in\,min} = 0.8$

$E_{in}$ 1.6 VDC OVERLOAD Temperature RM °F (25°C)

| $I_{in}$ Amp | $E_{out}$ Volt | $I_{out}$ Amp | Freq CPS | Ripple P-P MV | $P_{in}$ Watt | $P_{out}$ Watt | EFF % | $V_{CE}$ (sat) M Volt |
|---|---|---|---|---|---|---|---|---|
| 50.0 | 28 | 2.0 | 829 | 460 | 80.0 | 56 | 70.0 | |
| 62.0 | 28 | 2.5 | 819 | 800 | 99.2 | 70 | 70.5 | |
| 72.5 | 27.6 | 3.0 | 812 | 880 | 116.0 | 82.8 | 71.3 | |
| 82.0 | 26.7 | 3.5 | 791 | 750 | 131.2 | 93.5 | 71.2 | |
| 60.0 | 16.1 | 4.0 | 813 | 800 | 96.0 | 64.4 | 67.0 | |
| 10.2 | 0.2 | 4.3 | 873 | 300 | 16.3 | 0.86 | 5.3 | |
| | | | | | | | | |
| | | | | | | | | |
| | | | | | | | | |

$E_{in}$ 0.8 VDC Temperature -65 °F (-54°C)

| $I_{in}$ Amp | $E_{out}$ Volt | $I_{out}$ Amp | Freq CPS | Ripple P-P MV | $P_{in}$ Watt | $P_{out}$ Watt | EFF % | $V_{CE}$ (sat) M Volt |
|---|---|---|---|---|---|---|---|---|
| 25.6 | 27.3 | 0.535 | 443 | 270 | 20.5 | 14.6 | 71.2 | 34 |
| 32.8 | 27.3 | 0.715 | 445 | 290 | 26.2 | 19.5 | 74.4 | |
| 39.8 | 27.3 | 0.890 | 445 | 310 | 31.8 | 24.3 | 76.4 | |
| 47.6 | 27.3 | 1.07 | 436 | 250 | 38.1 | 29.2 | 76.6 | 43 |
| 55.1 | 27.3 | 1.25 | 432 | 240 | 44.1 | 34.1 | 77.3 | |
| 63.2 | 27.2 | 1.43 | 425 | 230 | 50.6 | 38.9 | 76.8 | |
| 70.5 | 27.0 | 1.61 | 420 | 250 | 56.4 | 43.5 | 77.1 | 48 |
| 78.5 | 26.8 | 1.79 | 420 | 320 | 62.8 | 48.0 | 76.4 | |
| 87.5 | 26.7 | 1.96 | 421 | 400 | 70.0 | 52.3 | 74.7 | |

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LIV Converter
EXG 2424
50 Watt

$E_{in(min)} = 0.8$

$E_{in}$ 0.9 VDC    Temperature -65 °F (-54°C)

| $I_{in}$ Amp | $E_{out}$ Volt | $I_{out}$ Amp | Freq CPS | Ripple P-P MV | $P_{in}$ Watt | $P_{out}$ Watt | EFF % | $V_{CE}$ (sat) M Volt |
|---|---|---|---|---|---|---|---|---|
| 23.4 | 27.6 | 0.535 | 500 | 600 | 21.1 | 14.8 | 70.1 | 34 |
| 30.0 | 27.6 | 0.715 | 492 | 540 | 27.0 | 19.7 | 72.9 | |
| 36.2 | 27.6 | 0.89 | 492 | 550 | 32.6 | 24.6 | 75.4 | |
| 42.7 | 27.5 | 1.07 | 494 | 490 | 38.4 | 29.4 | 76.5 | 42 |
| 49.2 | 27.5 | 1.25 | 487 | 560 | 44.3 | 34.4 | 77.6 | |
| 55.5 | 27.5 | 1.43 | 492 | 550 | 50.0 | 39.3 | 78.6 | |
| 63.0 | 27.5 | 1.61 | 476 | 550 | 56.7 | 44.4 | 78.0 | 47 |
| 70.0 | 27.4 | 1.79 | 477 | 600 | 63.0 | 49.0 | 77.7 | |
| 78.0 | 27.4 | 1.96 | 474 | 700 | 70.2 | 53.7 | 76.4 | |

$E_{in}$ 1.0 VDC    Temperature -65 °F

| $I_{in}$ Amp | $E_{out}$ Volt | $I_{out}$ Amp | Freq CPS | Ripple P-P MV | $P_{in}$ Watt | $P_{out}$ Watt | EFF % | $V_{CE}$ (sat) M Volt |
|---|---|---|---|---|---|---|---|---|
| 22.0 | 27.7 | 0.535 | 553 | 780 | 22.0 | 14.8 | 67.2 | 33 |
| 28.0 | 27.7 | 0.715 | 539 | 750 | 28.0 | 19.8 | 70.7 | |
| 33.2 | 27.7 | 0.89 | 513 | 800 | 33.2 | 24.7 | 74.3 | |
| 39.5 | 27.7 | 1.07 | 534 | 780 | 39.5 | 29.6 | 74.9 | 41 |
| 45.2 | 27.7 | 1.25 | 537 | 800 | 45.2 | 34.6 | 76.5 | |
| 51.8 | 27.7 | 1.43 | 544 | 600 | 51.8 | 39.6 | 76.4 | |
| 57.3 | 27.7 | 1.61 | 529 | 820 | 57.3 | 44.6 | 77.8 | 46 |
| 63.0 | 27.7 | 1.79 | 529 | 900 | 63.0 | 49.6 | 78.7 | |
| 70.5 | 27.7 | 1.96 | 517 | 950 | | 54.3 | 77.3 | |

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LIV Converter
EXG 2424
50 Watt
$E_{in(min)} = 0.8$

$E_{in}$ 1.1 VDC Temperature -65 °F (-54°C)

| $I_{in}$ Amp | $E_{out}$ Volt | $I_{out}$ Amp | Freq CPS | Ripple P-P MV | $P_{in}$ Watt | $P_{out}$ Watt | EFF % | $V_{CE}$ (sat) M Volt |
|---|---|---|---|---|---|---|---|---|
| 20.8 | 27.8 | 0.535 | 602 | 920 | 22.9 | 14.9 | 65.0 | 32 |
| 26.0 | 27.8 | 0.715 | 593 | 950 | 28.6 | 19.9 | 69.5 | |
| 31.0 | 27.8 | 0.89 | 591 | 950 | 34.1 | 24.7 | 72.4 | |
| 36.6 | 27.8 | 1.07 | 588 | 950 | 40.3 | 29.7 | 73.6 | 40 |
| 42.2 | 27.8 | 1.25 | 581 | 950 | 46.4 | 34.8 | 75.0 | |
| 47.5 | 27.8 | 1.43 | 581 | 1000 | 52.3 | 39.8 | 76.0 | |
| 53.0 | 27.8 | 1.61 | 575 | 1000 | 58.3 | 44.8 | 76.8 | 44 |
| 59.2 | 27.8 | 1.79 | 569 | 1000 | 65.1 | 49.8 | 76.8 | |
| 64.2 | 27.8 | 1.96 | 575 | 1200 | 70.6 | 54.5 | 77.1 | |

$E_{in}$ 1.2 VDC Temperature -65 °F

| $I_{in}$ Amp | $E_{out}$ Volt | $I_{out}$ Amp | Freq CPS | Ripple P-P MV | $P_{in}$ Watt | $P_{out}$ Watt | EFF % | $V_{CE}$ (sat) M Volt |
|---|---|---|---|---|---|---|---|---|
| 19.8 | 27.9 | 0.536 | 641 | 1020 | 23.8 | 14.9 | 62.6 | 32 |
| 24.5 | 27.9 | 0.715 | 650 | 1040 | 29.4 | 19.9 | 67.6 | |
| 29.3 | 27.9 | 0.89 | 640 | 1040 | 35.16 | 24.8 | 70.4 | |
| 34.2 | 27.9 | 1.07 | 637 | 1080 | 41.0 | 29.9 | 72.9 | 39 |
| 39.2 | 27.9 | 1.25 | 640 | 1100 | 47.0 | 34.9 | 74.2 | |
| 44.3 | 27.9 | 1.43 | 631 | 1120 | 53.2 | 39.9 | 75.0 | |
| 49.5 | 27.9 | 1.61 | 626 | 1150 | 59.4 | 44.9 | 75.5 | 43 |
| 55.0 | 27.9 | 1.79 | 619 | 1160 | 66.0 | 49.9 | 75.6 | |
| 60.2 | 27.9 | 1.96 | 639 | 1350 | 72.2 | 54.9 | 76.0 | |

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LIV Converter
EXG 2424
50 Watt

$E_{in\,min} = 0.8$

$E_{in}$ 1.3 VDC Temperature -65 °F (-54°C)

| $I_{in}$ Amp | $E_{out}$ Volt | $I_{out}$ Amp | Freq CPS | Ripple P-P MV | $P_{in}$ Watt | $P_{out}$ Watt | EFF % | $V_{CE}$ (sat) M Volt |
|---|---|---|---|---|---|---|---|---|
| 19.0 | 28 | 0.535 | 696 | 1160 | 24.7 | 15 | 60.7 | 32 |
| 23.2 | 28 | 0.715 | 696 | 1160 | 30.2 | 20 | 66.2 | |
| 27.5 | 28 | 0.89 | 694 | 1200 | 35.8 | 25 | 69.8 | |
| 32.2 | 28 | 1.07 | 690 | 1200 | 41.9 | 30 | 71.5 | 38 |
| 37.0 | 28 | 1.25 | 680 | 1200 | 48.1 | 35 | 72.7 | |
| 42.0 | 28 | 1.43 | 680 | 1220 | 54.5 | 40 | 73.6 | |
| 46.3 | 28 | 1.61 | 675 | 1250 | 60.2 | 45 | 74.7 | 42 |
| 51.0 | 28 | 1.79 | 673 | 1300 | 66.3 | 50 | 75.4 | |
| 56.0 | 28 | 1.96 | 668 | 1600 | 72.8 | 55 | 75.5 | |

$E_{in}$ 1.4 VDC Temperature -65 °F

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 18.0 | 28 | 0.535 | 750 | 1220 | 25.2 | 15 | 59.5 | 32 |
| 22.4 | 28 | 0.715 | 745 | 1240 | 31.4 | 20 | 63.6 | |
| 26.3 | 28 | 0.89 | 741 | 1250 | 36.8 | 25 | 67.9 | |
| 30.5 | 28 | 1.07 | 736 | 1250 | 42.7 | 30 | 70.2 | 37 |
| 35.0 | 28 | 1.25 | 735 | 1280 | 49.0 | 35 | 71.4 | |
| 39.3 | 28 | 1.43 | 731 | 1300 | 55.0 | 40 | 72.7 | |
| 43.5 | 28 | 1.61 | 729 | 1340 | 60.9 | 45 | 73.8 | 41 |
| 48.0 | 28 | 1.79 | 721 | 1400 | 67.2 | 50 | 74.4 | |
| 52.5 | 28 | 1.96 | 723 | 1540 | 73.5 | 55 | 75.0 | |

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LIV Converter
EXG 2424
50 Watt
$E_{in (min)} = 0.8$

$E_{in}$ 1.5 VDC — Temperature -65 °F (-54°C)

| $I_{in}$ Amp | $E_{out}$ Volt | $I_{out}$ Amp | Freq CPS | Ripple P-P MV | $P_{in}$ Watt | $P_{out}$ Watt | EFF % | $V_{CE}$ (sat) M Volt |
|---|---|---|---|---|---|---|---|---|
| 17.3 | 28 | 0.535 | 800 | 1320 | 26.0 | 15 | 57.6 | 32 |
| 21.3 | 28 | 0.715 | 791 | 1300 | 32.0 | 20 | 62.5 | |
| 26.0 | 28 | 0.89 | 791 | 1320 | 37.5 | 25 | 66.6 | |
| 29.2 | 28 | 1.07 | 783 | 1350 | 43.8 | 30 | 68.4 | 37 |
| 33.2 | 28 | 1.25 | 786 | 1360 | 49.8 | 35 | 70.2 | |
| 37.4 | 28 | 1.43 | 782 | 1380 | 56.1 | 40 | 71.3 | |
| 41.8 | 28 | 1.61 | 774 | 1400 | 62.7 | 45 | 71.7 | 40 |
| 45.4 | 28 | 1.79 | 773 | 1600 | 68.1 | 50 | 72.8 | |
| 49.5 | 28 | 1.96 | 773 | 1650 | 74.3 | 55 | 74.0 | |

$E_{in}$ 1.6 VDC — Temperature -65 °F

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 16.8 | 28 | 0.535 | 810 | 1300 | 26.9 | 15 | 55.7 | 32 |
| 20.5 | 28 | 0.715 | 810 | 1350 | 32.8 | 20 | 60.9 | |
| 24.1 | 28 | 0.89 | 811 | 1370 | 38.6 | 25 | 64.7 | |
| 27.5 | 28 | 1.07 | 816 | 1400 | 44.0 | 30 | 68.1 | 36 |
| 31.6 | 28 | 1.25 | 835 | 1410 | 50.6 | 35 | 69.1 | |
| 35.7 | 28 | 1.43 | 833 | 1440 | 57.1 | 40 | 70.0 | |
| 39.2 | 28 | 1.61 | 827 | 1480 | 62.7 | 45 | 71.9 | 39 |
| 43.0 | 28 | 1.79 | 825 | 1580 | 68.8 | 50 | 72.6 | |
| 47.2 | 28 | 1.96 | 818 | 1640 | 75.5 | 55 | 72.8 | |

[illegible] 10110
DATE 3-30-64

# LIV Converter
## EXG 2424
## 50 Watt

$E_{in(min)}$ = 0.8

$E_{in}$ 1.6 VDC OVERLOAD Temperature -65 °F (-54°C)

| $I_{in}$ Amp | $E_{out}$ Volt | $I_{out}$ Amp | Freq CPS | Ripple P-P MV | $P_{in}$ Watt | $P_{out}$ Watt | EFF % | $V_{CE}$ (sat) M Volt |
|---|---|---|---|---|---|---|---|---|
| 47.8 | 28 | 2.0 | 814 | 1700 | 76.5 | 56.0 | 73.2 | |
| 58.5 | 27.8 | 2.5 | 814 | 2250 | 93.6 | 69.5 | 74.2 | |
| 68.3 | 27.4 | 3.0 | 806 | 2450 | 109.3 | 82.2 | 75.2 | |
| 56.2 | 19.6 | 3.5 | 807 | 1520 | 91.7 | 68.6 | 72.4 | |
| 9.0 | 0.2 | 3.8 | 704 | 340 | 14.4 | .76 | 5.3 | |
| | | | | | | | | |
| | | | | | | | | |
| | | | | | | | | |
| | | | | | | | | |

$E_{in}$ 0.8 VDC Temperature 14 °F (-10°C)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 25.3 | 27.7 | 0.535 | 463 | 160 | 20.2 | 14.8 | 73.8 | 38 |
| 33.7 | 27.7 | 0.715 | 448 | 140 | 26.6 | 19.8 | 75.4 | |
| 39.7 | 27.7 | 0.890 | 456 | 150 | 31.8 | 24.7 | 77.6 | |
| 47.0 | 27.7 | 1.070 | 468 | 160 | 37.6 | 29.6 | 78.7 | 49 |
| 54.7 | 27.7 | 1.25 | 455 | 160 | 43.8 | 34.6 | 78.9 | |
| 62.5 | 27.7 | 1.43 | 444 | 150 | 50.0 | 39.6 | 79.2 | |
| 70.0 | 27.7 | 1.61 | 440 | 150 | 56.0 | 44.6 | 79.6 | 59 |
| 78.0 | 27.6 | 1.79 | 435 | 130 | 62.4 | 49.4 | 79.1 | |
| 84.5 | 27.3 | 1.96 | 426 | 120 | 67.6 | 53.5 | 79.1 | |

CRAM 10610
DATE 3-30-64

LIV Converter
EXG 2424
50 Watt
$E_{in(min)}$ = 0.8

$E_{in}$ 0.9 VDC Temperature 14 °F (-10°C)

| $I_{in}$ Amp | $E_{out}$ Volt | $I_{out}$ Amp | Freq CPS | Ripple P-P MV | $P_{in}$ Watt | $P_{out}$ Watt | EFF % | $V_{CE}$ (sat) M Volt |
|---|---|---|---|---|---|---|---|---|
| 23.2 | 27.9 | 0.535 | 516 | 240 | 20.9 | 14.9 | 71.2 | 37 |
| 30.0 | 27.9 | 0.715 | 504 | 230 | 27.0 | 19.9 | 73.7 | |
| 36.0 | 27.9 | 0.89 | 510 | 240 | 32.4 | 24.8 | 76.5 | |
| 43.0 | 27.9 | 1.07 | 504 | 250 | 38.7 | 29.9 | 77.2 | 47 |
| 49.5 | 27.9 | 1.25 | 507 | 250 | 44.6 | 34.9 | 78.2 | |
| 56.2 | 27.9 | 1.43 | 495 | 240 | 50.6 | 39.9 | 78.8 | |
| 62.9 | 27.8 | 1.61 | 493 | 250 | 56.6 | 44.8 | 79.1 | 58 |
| 70.0 | 27.8 | 1.79 | 487 | 250 | 63.0 | 49.8 | 79.0 | |
| 77.0 | 27.8 | 1.96 | 485 | 250 | 69.3 | 54.5 | 78.6 | |

$E_{in}$ 1.0 VDC Temperature 14 °F

| $I_{in}$ Amp | $E_{out}$ Volt | $I_{out}$ Amp | Freq CPS | Ripple P-P MV | $P_{in}$ Watt | $P_{out}$ Watt | EFF % | $V_{CE}$ (sat) M Volt |
|---|---|---|---|---|---|---|---|---|
| 21.9 | 28.0 | 0.535 | 565 | 300 | 21.9 | 15 | 68.4 | 36 |
| 27.8 | 28.0 | 0.715 | 567 | 300 | 27.8 | 20 | 71.9 | |
| 33.3 | 28.0 | 0.89 | 568 | 305 | 33.3 | 25 | 75.0 | |
| 39.2 | 28.0 | 1.07 | 550 | 300 | 39.2 | 30 | 76.5 | 44 |
| 45.2 | 28.0 | 1.25 | 551 | 310 | 45.2 | 35 | 77.4 | |
| 51.3 | 28.0 | 1.43 | 549 | 325 | 51.3 | 40 | 77.9 | |
| 57.5 | 28.0 | 1.61 | 544 | 330 | 57.5 | 45 | 78.2 | 56 |
| 13.2 | 28.0 | 1.79 | 543 | 335 | 63.2 | 50 | 79.1 | |
| 10.1 | 28.0 | 1.96 | 533 | 345 | 70.1 | 55 | 78.4 | |

OEXM 10610
DATE 3-30-64

LIV Converter
EXG 2424
50 Watt
$E_{in(min)} = 0.8$

$E_{in}$ 1.1 VDC Temperature 14 °F (-10°C)

| $I_{in}$ Amp | $E_{out}$ Volt | $I_{out}$ Amp | Freq CPS | Ripple P-P MV | $P_{in}$ Watt | $P_{out}$ Watt | EFF % | $V_{CE}$ (sat) M Volt |
|---|---|---|---|---|---|---|---|---|
| 20.9 | 28 | 0.535 | 607 | 340 | 23.0 | 15 | 65.2 | 35 |
| 26.0 | 28 | 0.715 | 611 | 360 | 28.6 | 20 | 69.9 | |
| 31.0 | 28 | 0.89 | 610 | 360 | 34.1 | 25 | 73.0 | |
| 36.8 | 28 | 1.07 | 603 | 360 | 40.5 | 30 | 74.0 | 42 |
| 42.1 | 28 | 1.25 | 598 | 370 | 46.3 | 35 | 75.5 | |
| 48.0 | 28 | 1.43 | 599 | 380 | 52.8 | 40 | 76.0 | |
| 53.2 | 28 | 1.61 | 593 | 390 | 58.5 | 45 | 76.9 | 53 |
| 58.9 | 28 | 1.79 | 609 | 400 | 64.8 | 50 | 77.1 | |
| 64.3 | 28 | 1.96 | 590 | 420 | 70.7 | 55 | 77.8 | |

$E_{in}$ 1.2 VDC Temperature 14 °F

| $I_{in}$ Amp | $E_{out}$ Volt | $I_{out}$ Amp | Freq CPS | Ripple P-P MV | $P_{in}$ Watt | $P_{out}$ Watt | EFF % | $V_{CE}$ (sat) M Volt |
|---|---|---|---|---|---|---|---|---|
| 19.6 | 28 | 0.535 | 668 | 380 | 23.5 | 15 | 63.8 | 35 |
| 24.1 | 28 | 0.715 | 662 | 385 | 28.9 | 20 | 69.2 | |
| 29.0 | 28 | 0.89 | 663 | 400 | 34.8 | 25 | 71.8 | |
| 34.0 | 28 | 1.07 | 657 | 410 | 40.8 | 30 | 73.5 | 41 |
| 39.2 | 28 | 1.25 | 653 | 420 | 47.0 | 35 | 74.4 | |
| 44.2 | 28 | 1.43 | 649 | 430 | 53.0 | 40 | 75.4 | |
| 49.3 | 28 | 1.61 | 657 | 440 | 59.2 | 45 | 76.0 | 50 |
| 54.5 | 28 | 1.79 | 640 | 450 | 65.4 | 50 | 76.4 | |
| 59.3 | 28 | 1.96 | 644 | 480 | 71.2 | 55 | 77.2 | |

OEXM 10610
DATE 3-30-64

LIV Converter
EXG 2424
50 Watt
$E_{in(min)} = 0.8$

$E_{in}$ 1.3 VDC Temperature 14 °F (-10°C)

| $I_{in}$ Amp | $E_{out}$ Volt | $I_{out}$ Amp | Freq CPS | Ripple P-P MV | $P_{in}$ Watt | $P_{out}$ Watt | EFF % | $V_{CE}$ (sat) M Volt |
|---|---|---|---|---|---|---|---|---|
| 18.9 | 28 | 0.535 | 715 | 420 | 24.6 | 15 | 60.9 | 34 |
| 23.3 | 28 | 0.715 | 712 | 425 | 30.3 | 20 | 66.0 | |
| 27.8 | 28 | 0.89 | 710 | 430 | 36.1 | 25 | 69.2 | |
| 32.5 | 28 | 1.07 | 704 | 440 | 42.3 | 30 | 70.9 | 40 |
| 37.0 | 28 | 1.25 | 692 | 450 | 48.1 | 35 | 72.7 | |
| 41.7 | 28 | 1.43 | 700 | 465 | 54.2 | 40 | 73.8 | |
| 46.4 | 28 | 1.61 | 692 | 480 | 60.3 | 45 | 74.6 | 48 |
| 51.3 | 28 | 1.79 | 699 | 500 | 66.7 | 50 | 74.9 | |
| 55.8 | 28 | 1.96 | 692 | 530 | 72.5 | 55 | 75.8 | |

$E_{in}$ 1.4 VDC Temperature 14 °F

| $I_{in}$ Amp | $E_{out}$ Volt | $I_{out}$ Amp | Freq CPS | Ripple P-P MV | $P_{in}$ Watt | $P_{out}$ Watt | EFF % | $V_{CE}$ (sat) M Volt |
|---|---|---|---|---|---|---|---|---|
| 18.1 | 28 | 0.535 | 772 | 440 | 25.3 | 15 | 59.2 | 34 |
| 22.3 | 28 | 0.715 | 756 | 450 | 31.2 | 20 | 64.1 | |
| 26.2 | 28 | 0.89 | 766 | 460 | 36.7 | 25 | 68.1 | |
| 30.5 | 28 | 1.07 | 760 | 480 | 42.7 | 30 | 70.2 | 39 |
| 34.8 | 28 | 1.25 | 759 | 485 | 48.7 | 35 | 71.8 | |
| 39.4 | 28 | 1.43 | 752 | 490 | 55.2 | 40 | 72.4 | |
| 43.8 | 28 | 1.61 | 747 | 500 | 61.3 | 45 | 73.4 | 46 |
| 48.1 | 28 | 1.79 | 745 | 520 | 67.3 | 50 | 74.2 | |
| 52.7 | 28 | 1.96 | 748 | 560 | 73.8 | 55 | 74.5 | |

OEXM 10610
DATE 3-30-64

LIV Converter
EXG 2424
50 Watt

$E_{in(min)} = 0.8$

$E_{in}$ 1.5 VDC Temperature 14 °F (-10°C)

| $I_{in}$ Amp | $E_{out}$ Volt | $I_{out}$ Amp | Freq CPS | Ripple P-P MV | $P_{in}$ Watt | $P_{out}$ Watt | EFF % | $V_{CE}$ (sat) M Volt |
|---|---|---|---|---|---|---|---|---|
| 17.5 | 28 | 0.535 | 821 | 470 | 26.3 | 15 | 57.0 | 33 |
| 21.6 | 28 | 0.715 | 820 | 490 | 32.4 | 20 | 61.7 | |
| 25.1 | 28 | 0.89 | 814 | 500 | 37.7 | 25 | 66.3 | |
| 29.3 | 28 | 1.07 | 810 | 500 | 44.0 | 30 | 68.1 | 38 |
| 33.3 | 28 | 1.25 | 805 | 510 | 50.0 | 35 | 70.0 | |
| 37.5 | 28 | 1.43 | 801 | 520 | 56.3 | 40 | 71.0 | |
| 41.5 | 28 | 1.61 | 804 | 540 | 62.3 | 45 | 72.2 | 45 |
| 45.8 | 28 | 1.79 | 794 | 560 | 68.7 | 50 | 72.7 | |
| 50.0 | 28 | 1.96 | 791 | 590 | 75.0 | 55 | 73.3 | |

$E_{in}$ 1.6 VDC Temperature 14 °F

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 17.0 | 28.2 | 0.535 | 870 | 480 | 27.2 | 15.1 | 55.5 | 33 |
| 20.5 | 28 | 0.715 | 864 | 500 | 32.8 | 20 | 60.9 | |
| 24.3 | 28 | 0.89 | 864 | 510 | 38.9 | 25 | 64.2 | |
| 28.0 | 28 | 1.07 | 865 | 520 | 44.8 | 30 | 66.9 | 37 |
| 31.8 | 28 | 1.25 | 856 | 540 | 50.9 | 35 | 68.7 | |
| 35.8 | 28 | 1.43 | 858 | 550 | 57.3 | 40 | 69.8 | |
| 40.2 | 28 | 1.61 | 850 | 560 | 64.3 | 45 | 70.1 | 44 |
| 44.2 | 28 | 1.79 | 853 | 590 | 70.7 | 50 | 70.7 | |
| 48.1 | 28 | 1.96 | 848 | 630 | 77.0 | 55 | 71.4 | |

CDXM 10610
DATE 3-30-64

LIV Converter
EXG 2424
50 Watt

$E_{in}$ 1.6 VDC OVERLOAD Temperature 14 °F (-10°C)

| $I_{in}$ Amp | $E_{out}$ Volt | $I_{out}$ Amp | Freq CPS | Ripple P-P MV | $P_{in}$ Watt | $P_{out}$ Watt | EFF % | $V_{CE}$ (sat) M Volt |
|---|---|---|---|---|---|---|---|---|
| 48.9 | 28 | 2.0 | 828 | 680 | 78.2 | 56.0 | 71.6 | |
| 61.0 | 28.0 | 2.5 | 814 | 1100 | 97.6 | 70.0 | 71.7 | |
| 69.9 | 27.1 | 3.0 | 809 | 1180 | 111.8 | 81.3 | 72.7 | |
| 79.0 | 26.4 | 3.5 | 792 | 980 | 126.4 | 92.4 | 73.1 | |
| 38.4 | 9.5 | 4.0 | 836 | 800 | 61.4 | 38.0 | 61.8 | |
| 10.0 | 0.2 | 4.1 | 864 | 350 | 16.0 | 0.82 | 5.0 | |
| | | | | | | | | |
| | | | | | | | | |
| | | | | | | | | |

$E_{in}$ 1.6 VDC OVERLOAD Temperature 158 °F (70°C)

| $I_{in}$ Amp | $E_{out}$ Volt | $I_{out}$ Amp | Freq CPS | Ripple P-P MV | $P_{in}$ Watt | $P_{out}$ Watt | EFF % | $V_{CE}$ (sat) M Volt |
|---|---|---|---|---|---|---|---|---|
| 50.8 | 28.0 | 2.0 | 831 | 420 | 81.3 | 56.0 | 68.9 | |
| 63.0 | 28.0 | 2.5 | 816 | 740 | 100.8 | 70.0 | 69.4 | |
| 74.0 | 27.6 | 3.0 | 803 | 820 | 118.4 | 82.8 | 69.9 | |
| 82.0 | 26.3 | 3.5 | 793 | 620 | 131.2 | 92.1 | 70.1 | |
| 9.5 | 0.2 | 3.9 | 896 | 290 | 15.2 | .78 | 5.1 | |
| | | | | | | | | |
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# APPENDIX B

# PRELIMINARY LOW INPUT VOLTAGE CONVERTER-REGULATOR RELIABILITY ESTIMATES

## RELIABILITY ESTIMATES

One of the prime reasons for using a low input voltage converter-regulator is to improve the basic reliability of the power system. To effectively determine the proper application and configuration of source-converter-regulator systems it is necessary to have estimated reliabilities of the various system components. To provide preliminary information for system design, calculated converter-regulator reliabilities have been based upon the following assumptions:

1. All parts are derated by 50%.
2. The catastrophic failure of any one part results in failure of the converter.
3. Resistors are carbon composition or equivalent.
4. Capacitors are tantalum or equivalent.
5. All diodes are silicon.
6. Minuteman semiconductor minimum listed failure rates were used for the 25° C condition although the temperature associated with these minimums is considerably above 25° C.

The data source for standard military parts is the "RADC Reliability Notebook" (Rev. 12/31/61). The data source for Minuteman parts is the "Autonetics Minuteman Standard Parts Handbook".

A detailed breakdown of the estimates is shown below. It should be noted, however, that just the use of Minuteman parts does not mean the present design can achieve these reliability levels. An active reliability program is basic to the achievement of these low failure rates. Even the achievement of the indicated standard military parts estimate is dependent upon an active reliability program as well as qualification of the Honeywell transistors for military and space applications.

## STANDARD MILITARY PARTS

### Regulator

| Item | Number | Fr (% /1000 hrs.) 25°C | Fr (% /1000 hrs.) 50°C | $NF_r$ (% /1000 hrs.) 25°C | $NF_r$ (% /1000 hrs.) 50°C |
|---|---|---|---|---|---|
| Resistors (carbon composition) | 31 | .001 | .002 | .031 | .062 |
| Capacitors (tantalum) | 11 | .012 | .031 | .132 | .341 |
| Transistors | 11 | .056 | .066 | 616 | .726 |
| Diodes | 18 | .028 | .033 | .504 | .594 |
| Solder Joints | 45 | .001 | .001 | .045 | .045 |

25° C: $\Sigma$ $NF_r$ = 1.328% /1000 hrs; MTBF = 75,400 hrs.

50° C: $\Sigma$ $NF_r$ = 1.768% /1000 hrs; MTBF = 56,600 hrs.

### Basic Converter

| Item | Number | Fr 25°C | Fr 50°C | $NF_r$ 25°C | $NF_r$ 50°C |
|---|---|---|---|---|---|
| Resistors (carbon composition) | 3 | .001 | .002 | .003 | .006 |
| (power w.w.) | 1 | .043 | .053 | .043 | .053 |
| Capacitors (tantalum) | 4 | .012 | .031 | .048 | .124 |
| Transformers | 3 | .050 | .050 | .150 | .150 |
| Chokes | 2 | .050 | .050 | .100 | .100 |
| Transistors | 5 | .056 | .066 | .280 | .330 |
| Diodes | 12 | .028 | .033 | .336 | .395 |
| Solder Joints | 55 | .001 | .001 | .055 | .055 |

25° C: $\Sigma$ $NF_r$ = 1.015% /1000 hrs; MTBF = 98,500 hrs.

50° C: $\Sigma$ $NF_r$ = 1.214% /1000 hrs; MTBF = 82,400 hrs.

### Entire Converter

25° C: $\Sigma$ $NF_r$ = 2.343% /1000 hrs; MTBF = 42,700 hrs.

50° C: $\Sigma$ $NF_r$ = 2.945% /1000 hrs; MTBF = 33,500 hrs.

## MINUTEMAN LEVEL PARTS

### Regulator

| Item | Number | Fr (% /1000 hrs.) 25° C | Fr (% /1000 hrs.) 50° C | $NF_r$ (% /1000 hrs.) 25° C | $NF_r$ (% /1000 hrs.) 50° C |
|---|---|---|---|---|---|
| Resistors (carbon composition) | 31 | .0001 | .0001 | .0031 | .0031 |
| Capacitors (tantalum) | 11 | .003 | .0052 | .0330 | .0572 |
| Transistors (Unijunction) | 1 | .010 | .010 | .0100 | .0100 |
| (Si.) | 8 | .001 | .001 | .0080 | .0080 |
| (Ge.) | 2 | .003 | .003 | .0060 | .0060 |
| Diodes (Si.) | 13 | .001 | .001 | .0130 | .0130 |
| Diodes (Reference) | 5 | .002 | .002 | .0100 | .0100 |
| Solder Joints | 45 | .001 | .001 | .0450 | .0450 |

$$25^\circ C: \sum NF_r = .1281\% \ /1000 \text{ hrs}; \ MTBF = \frac{1}{\sum NF_r} = 787,000 \text{ hrs.}$$

$$50^\circ C: \sum NF_r = .1523\% \ /1000 \text{ hrs}; \ MTBF = \frac{1}{\sum NF_r} = 657,000 \text{ hrs.}$$

### Basic Converter

| | | | | | |
|---|---|---|---|---|---|
| Resistors (carbon composition) | 3 | .0001 | .0001 | .0003 | .0003 |
| (power w.w.) | 1 | .0007 | .0010 | .0007 | .0010 |
| Capacitors (tantalum) | 4 | .008 | .0052 | .0120 | .0208 |
| Chokes | 2 | .0004 | .0005 | .0008 | .0010 |
| Transformers (T1) | 1 | .0008 | .0009 | .0008 | .0009 |
| (T2) | 1 | .0011 | .0013 | .0011 | .0013 |
| (T3) | 1 | .0025 | .0029 | .0025 | .0029 |
| Transistors (Ge) | 5 | .003 | .0030 | .0150 | .0150 |
| Diodes (Si) | 12 | .001 | .001 | .0120 | .0120 |
| Solder Joints | 55 | .001 | .001 | .0550 | .0550 |

$25^\circ C: \sum NF_r = .1002\%$ /1000 hrs; MTBF = 998,000 hrs.

$50^\circ C: \sum NF_r = .1102\%$ /1000 hrs; MTBF = 907,400 hrs.

### Entire Converter

$25^\circ C: \sum NF_r = .2283\%$ /1000 hrs; MTBF = 438,000 hrs.

$50^\circ C: \sum NF_r = .2625\%$ /1000 hrs; MTBF = 381,000 hrs.

# APPENDIX C

## EXG 2424E1X1

## CONVERTER REGULATOR PARTS LIST

ENGINEERING PARTS LIST
EXG 2424E1X1
CONVERTER REGULATOR

| PART NO. | PART NAME | RATING | DESIGNATION | QUANTITY |
|---|---|---|---|---|
| 100 OHM | RESISTOR | .1 WATT | R1 | 1 |
| 22 OHM | RESISTOR | 1/2 WATT | R2 | 1 |
| 12 OHM | RESISTOR | 1 WATT | R3 | 1 |
| 33K OHM | RESISTOR | .1 WATT | R4 | 1 |
| 560 OHM | RESISTOR | .1 WATT | R5 | 1 |
| 150 OHM | RESISTOR | .1 WATT | R8 | 1 |
| 4.7K OHM | RESISTOR | .1 WATT | R9 | 1 |
| 470 OHM | RESISTOR | .1 WATT | R10 | 1 |
| 3.3K OHM | RESISTOR | .1 WATT | R11 | 1 |
| 6.8K OHM | RESISTOR | .1 WATT | R12 | 1 |
| 16K OHM | RESISTOR | .1 WATT | R13 | 1 |
| 390 OHM | RESISTOR | .1 WATT | R14 | 1 |
| 5.1K OHM | RESISTOR | .1 WATT | R15 | 1 |
| 4.3K OHM | RESISTOR | .1 WATT | R17 | 1 |
| 2.2K OHM | RESISTOR | .1 WATT | R18, R34 | 2 |
| 10K OHM | RESISTOR | .1 WATT | R19, R20 | 2 |
| 680 OHM | RESISTOR | .1 WATT | R21 | 1 |
| 1K OHM | RESISTOR | .1 WATT | R22,R24,R25,R28 | 4 |
| 5K OHM | POTENTIOMETER | 1/4 WATT | R23 | 1 |
| 47K OHM | RESISTOR | .1 WATT | R26, R29 | 2 |

ENGINEERING PARTS LIST
(Continued)

| PART NO. | PART NAME | RATING | DESIGNATION | QUANTITY |
|---|---|---|---|---|
| 5K OHM | RESISTOR | 1.0 WATT | R27 | 1 |
| 500 OHM | POTENTIOMETER | 1/4 WATT | R30 | 1 |
| 18K OHM | RESISTOR | .1 WATT | R31, R32 | 2 |
| 2.7K OHM | RESISTOR | .1 WATT | R33 | 1 |
| .025 OHM | RESISTOR | 3 WATT | R35 | 1 |
| .01 MFD | CAPACITOR | 35 VDCW | C1, C15 | 2 |
| 10 MFD | CAPACITOR | 35 VDCW | C2, C12, C14 | 3 |
| 100 MFD | CAPACITOR | 35 VDCW | C3 | 1 |
| 750 MFD | CAPACITOR | 60 VDCW | C4 | 1 |
| 1 MFD | CAPACITOR | 35 VDCW | C5, C8, C13 | 3 |
| 1000 MFD | CAPACITOR | 40 VDCW | C6 | 1 |
| .33 MFD | CAPACITOR | 35 VDCW | C7 | 1 |
| .1 MFD | CAPACITOR | 35 VDCW | C9 | 1 |
| .15 MFD | CAPACITOR | 35 VDCW | C10 | 1 |
| .001 MFD | CAPACITOR | 35 VDCW | C11 | 1 |
| IN645 | DIODE | 400 M.A. | CR1,2,3,4,5, 15,16,18,19, 20,21,23,25,26 | 14 |
| IN3189 | DIODE | 1 AMP | CR6, CR7 | 2 |
| TIX441 | DIODE | 6 AMPS | CR8,CR9,CR14 | 3 |
| IN3038B | ZENER DIODE | 1 WATT | CR10 | 1 |
| IN643A | DIODE | 200 M.W. | CR11, CR12 | 2 |
| IN823 | ZENER DIODE | 400 M.W. | CR17,22,29 | 3 |
| IN697B | ZENER DIODE | 200 M.W. | CR30 | 1 |

## ENGINEERING PARTS LIST
(Continued)

| PART NO. | PART NAME | RATING | DESIGNATION | QUANTITY |
|---|---|---|---|---|
| 2N2000 | TRANSISTOR | | Q1 | 1 |
| MHT 2202 | TRANSISTOR | | Q2, Q3,Q4,Q5 | 4 |
| 2N2833 | TRANSISTOR | | Q6 | 1 |
| 2N2468 | TRANSISTOR | | Q7 | 1 |
| 2N489 | TRANSISTOR | | Q8 | 1 |
| 2N720 | TRANSISTOR | | Q9, Q13 | 2 |
| 2N718 | TRANSISTOR | | Q10,11,14,15 16 | 5 |
| 2N3019 | TRANSISTOR | | Q12 | 1 |
| | PULSE TRANSFORMER | | T1 | 1 |
| | FEEDBACK TRANSFORMER | | T2 | 1 |
| | POWER TRANSFORMER | | T3 | 1 |
| | TIMING REACTOR | | L1 | 1 |
| | CHOKE COIL | | L2 | 1 |
| D653 | BASE | | | 1 |
| D372 | COVER | | | 1 |
| 4016-1 | SOLDER STRAP | | | 2 |
| C374 | BRACKET-REGULATOR | | | 1 |
| 516662 | BAR-TERMINAL-NEG | | | 1 |
| 4016-2 | CONDUCTOR | | | 2 |

ENGINEERING PARTS LIST
(Continued)

| PART NO. | PART NAME | RATING | DESIGNATION | QUANTITY |
|---|---|---|---|---|
| 4016-3 | BRACKET-CLAMP | | | 2 |
| 516642 | CLAMP | | | 2 |
| 4016-4 | BRACKET-TRANSISTOR | | | 1 |
| 4016-5 | BRACKET-CHOKE | | | 1 |
| 4016-6 | COVER-REGULATOR | | | 1 |
| 516651 | BAR-TERMINAL-POS | | | 1 |
| 4016-7 | TERMINAL BOARD | | | 1 |
| 516660 | BAR BUS-LEFT | | | 1 |
| 516654 | BAR BUS-RIGHT | | | 1 |